Abstract

Visual working memory is typically characterized by severe capacity limitations. Evidence from laboratory experiments has suggested that visual working memory can hold only three or four objects at a time (Luck & Vogel, 1997). The efficient use of visual working memory capacity largely depends on selective attention, which enables preferential encoding and maintenance of a subset of the available information.

One major approach to studying the role of visual attention in visual working memory has been to use the cued change detection paradigm. Some studies have showed that a location cue given before (precue) or shortly after (iconic cue) a memory display improves visual working memory at the cued location (e.g., Woodman, Vecera, & Luck, 2003). Other studies have demonstrated that location cues presented long after memory display offset (retro-cue) are also effective in biasing visual working memory performance (e.g., Griffin & Nobre, 2003). Previous research has made significant progress in understanding the role of attention in visual working memory. Meanwhile, many new questions arise. The present dissertation investigates three important issues on attentional control over visual working memory by modifying and extending the cued change detection paradigm.

The first issue concerns the commonality and differences between space-based selection and feature-based selection within visual working memory. Several studies have examined the effect of space-based selection on visual working memory encoding and maintenance by comparing location pre- and retro-cues in change detection tasks (e.g., Griffin & Nobre, 2003; Nobre et al., 2004). Their results showed considerable similarities between pre- and retro-cueing, indicating that selective encoding of perceptual representations and selective maintenance of mental representations may rely on a common spatial attention mechanism. However, studies so far have exclusively compared pre- and retro-cues within space-based selection, leaving open the question of whether the findings in space-based selection generalize to other types of attentional selection such as feature-based selection. Comparing different types of attentional selection is a necessary step to attaining a complete understanding of the laws governing attentional selection within visual working memory. The first study in this dissertation addressed this issue by systematically comparing feature-based and location-based selection in the context of visual working memory. Participants were given color or

location pre- and retro-cues in change detection tasks. The results reveal that color-based and location-based modes of attentional selection differently influence visual working memory encoding and maintenance. Color-based selection modulated visual working memory performance to a greater extent during encoding than during maintenance, whereas the effect of location-based modulation was equivalent in these two cases. The results of location-based selection support the notion of a common mechanism of spatial attention underlying visual working memory encoding and maintenance. In contrast, different mechanisms may exist for color-based selection in these two cases. Furthermore, color-based selection was even more efficient than location-based modulation during visual working memory encoding. This finding is consistent with research on perceptual attention suggesting that feature-based attentional modulation reflects a combination of boosting sensory gain and sharpening neuronal tuning, whereas location-based attention operates mainly by boosting sensory gain (Ling, Liu, & Carrasco, 2009; Treue & Martínez-Trujillo, 1999). Alternatively, this may relate to different processing efficiency between color and location information. Perhaps encoding color is less efficient than encoding location, leading to participants relying on color precues to a greater extent than location precues. Another novel finding is that during visual working memory maintenance, location-based selection was more efficient than color-based selection, but only when the task required memorizing complex triple-conjunction stimuli. When stimuli were simple color-location conjunction objects, there was no difference in cueing efficiency between color-based and location-based selection. These results appear to be in accord with the hypothesis of location-based organization of visual working memory representations.

The second issue discussed in this dissertation is on reorienting attention within visual working memory representations. Retro-cue studies have demonstrated that attentional selection can operate upon mental representations held in visual working memory. A corollary issue to the question of how attentional selection takes places within visual working memory concerns the fate of unattended representations. Are unattended representations obligatorily banished from visual working memory or are they still stored but deactivated until attention is reorient to them? Previous studies reported conflicting results regarding whether attention can be reoriented to unattended mental representations (Landman, Spekreijse, & Lamme, 2003; Matsukura, Luck, & Vecera, 2007). The second study in this dissertation was designed to investigate

sequential shifts of attention among visual working memory representations. Participants were cued to attend one location after the offset of a memory array, and in some trials, further cued to reorient attention within visual working memory. Outcomes across experiments consistently show that the second attentional cues facilitated memory, confirming the hypothesis that attending one representation in visual working memory does not render the other uncued representations unavailable (Landman et al., 2003). Interestingly, facilitative effects of the first attentional cue persisted even when attention was redirected to other representations. Further investigation reveals that the magnitude of the first cue benefit can be manipulated by cue validity. But reducing the first cue validity diminished but did not completely vanish the first cue benefit, indicating that the first cue benefit might have been preserved both partially under automatic control and partially under voluntary control.

The final issue is concerned with voluntary control over dimension-selective binding within visual working memory representations. Few studies have been carried out to investigate this issue and inconsistent results have been reported (Kondo & Saiki, 2012; Logie, Brockmole, & Jaswal, 2011). In the study of Logie et al. (2011), one object dimension (location, shape, or color) was designated task irrelevant and was randomized between memory and probe displays. At short retention intervals (≦1000 ms), randomizing the task-irrelevant dimension caused a significant interference to memory of bindings between the remaining dimensions regardless of whether location, color or shape was the task-irrelevant dimension, but randomizing location was more disruptive than randomizing shape or color. In contrast, at long intervals (≧1500 ms), binding memory was not interfered by randomizing any of the three dimensions. Logie et al. thus suggested that location plays a central role in perceptual binding, but does have special status in visual working memory and any dimension can be excluded according to task demands. However, there is also evidence to suggest a differentiate status of location from other nonspatial features. Kondo and Saiki (2012) demonstrated that asking participants to ignore location disrupted memory for color-shape bindings, whereas asking them to ignore color or shape did not interfere with memory for binding between the remaining dimensions (i.e., shape-location binding; color-location binding). This pattern of results indicates that color and shape can be excluded, but location cannot be excluded from visual working memory representations, and therefore suggests that location plays a privileged role in the organization of visual working

memory representations. At present very few empirical data on dimension-selectivity of visual working memory have been reported, and the divergent results from previous studies highlight the need for further investigation. The third study was therefore conducted to clarify whether partial representations composed of only task-relevant dimensions can be formed and maintained in visual working memory. Furthermore, because behavioral data are ambiguous as whether the voluntary manipulation operates on memory maintenance or memory retrieval, EEG was recorded during task performance to provide a real-time measurement of the dynamics of dimension-selective binding within visual working memory. Behavioral data revealed that ignoring location impaired performance, but ignoring color or shape improved performance, suggesting that locations are indispensable to form and maintain VWM representations. More convincingly, neural correlates for these behavioral effects were found: behavioral impairments by ignoring location were correlated with reduced CDA amplitude while behavioral improvements by ignoring color or shape were associated with increased frontal midline theta amplitude during the maintenance period. These results provide evidence for the notion of location-based organization of visual working memory representations, and also have important implications for understanding the functional units of visual working memory.

The results from the three studies reveal new aspects of the interaction between visual attention and visual working memory, and also provide important implications for the structural properties of visual working memory representations. The picture emerging from the present studies is that the ability to voluntarily modulate visual working memory contents is much more extensive than previously believed. While there are still many unresolved issues, the results to date are very encouraging. Further research is needed to understand the full range of interactions between visual attention and visual working memory and might benefit from an approach along the lines used in the present dissertation.