Exploring the symmetry and temporal dynamics of verbal-spatial bindings in working memory

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Introduction

- Campo et al. (2010) recently demonstrated a verbal-spatial *binding asymmetry*: when presented with arrays of consonants in distinct locations, participants bound letters to locations when directed to remember the letters in the display, but not when directed to remember the set of locations.
- This finding may represent a *true* asymmetry such that the processing of 'what' necessarily entails binding to 'where', while the pattern of filled locations may be serve as empty place-markers when 'where' is the subject of the task (Treisman & Zhang, 2006). We refer to this position as the **strong asymmetry hypothesis**.
- Alternatively, the asymmetry may represent a still-frame of a dynamic binding process that had only partially completed at test. Logie, Brockmole and Jaswal (2011) recently provided evidence that task-irrelevant features could be inhibited from consolidated memory representations – a process that took longer for spatial features (circa 1500ms) than for visual features (circa 1000ms post stimulus offset). As Campo et al. (2010) used a fixed retention interval (1200ms), the inhibition process may have still been underway when memory was probed in the verbal task, or already completed in the spatial task. We refer to this as the **asymmetrical inhibition hypothesis**.
- Using a modified version of Campo et al.'s (2010) paradigm with a variable retention interval between display and test (200ms-15s), we contrasted these two propositions. Given arrays of four letters in locations, participants either remembered the letters in the display (the verbal task) or the locations in the display (the spatial task).

The **strong asymmetry hypothesis:** predicts binding in the verbal task but not the spatial task (with binding in the verbal task potentially diminishing over time).

The **asymmetrical inhibition hypothesis**: makes similar predictions regarding the verbal task; however, there may be binding in the spatial task at shorter but not longer retention intervals (on the basis that task-irrelevant verbal information may be inhibited from spatial representations relatively quickly).

Method

- **The Verbal Task:** Participants judged whether the a single probe represented at letter that was present in the memory display (regardless of location).
- **The Spatial Task:** Participants judged whether the single probe represented a letter that was filled in the memory display (regardless of letter).
- Two critical probe types assessed binding (See **Figure 1**):
  - **Intact probes:** a letter presented in its initial location (bindings preserved).
  - **Recombined probes:** a letter and location re-combine to form the probe (bindings switched).

Binding predicts superior performance in the intact condition relative to the recombined condition – the so called binding effect.

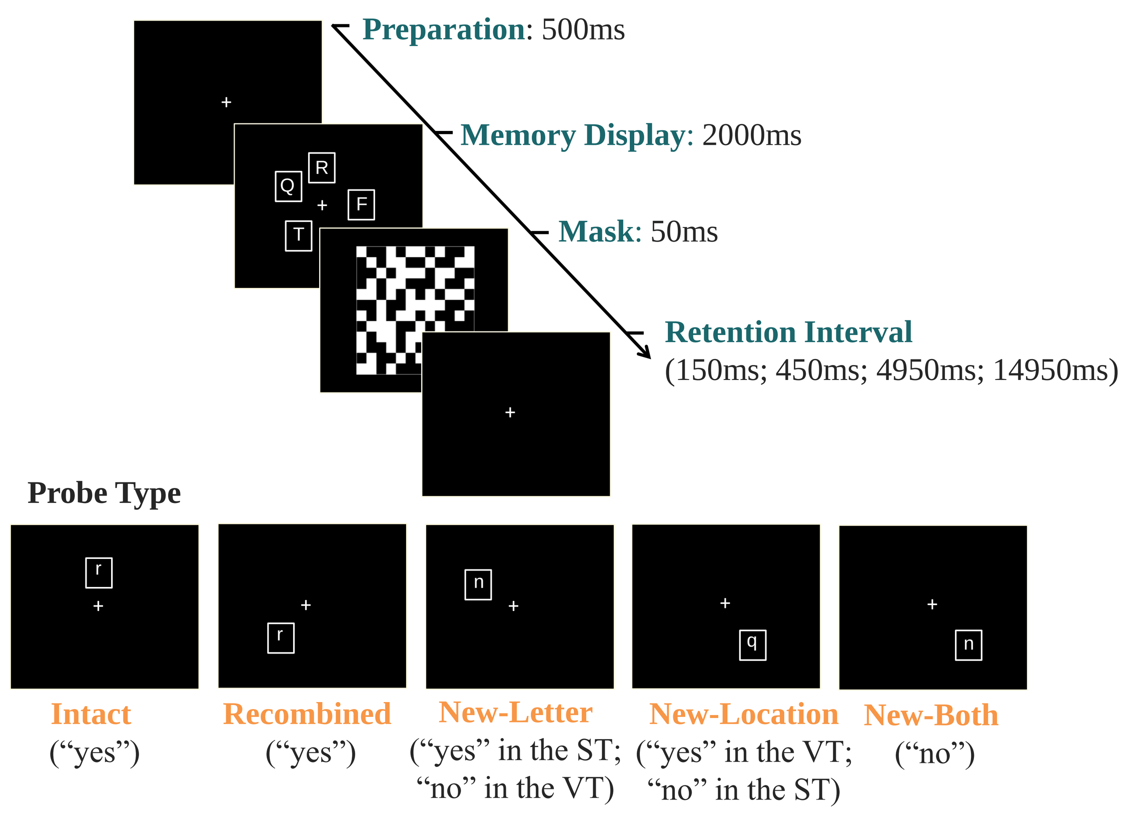

Figure 1. *Schematic illustration of trial types in the visual task (VT) and the spatial task (ST).*

Results

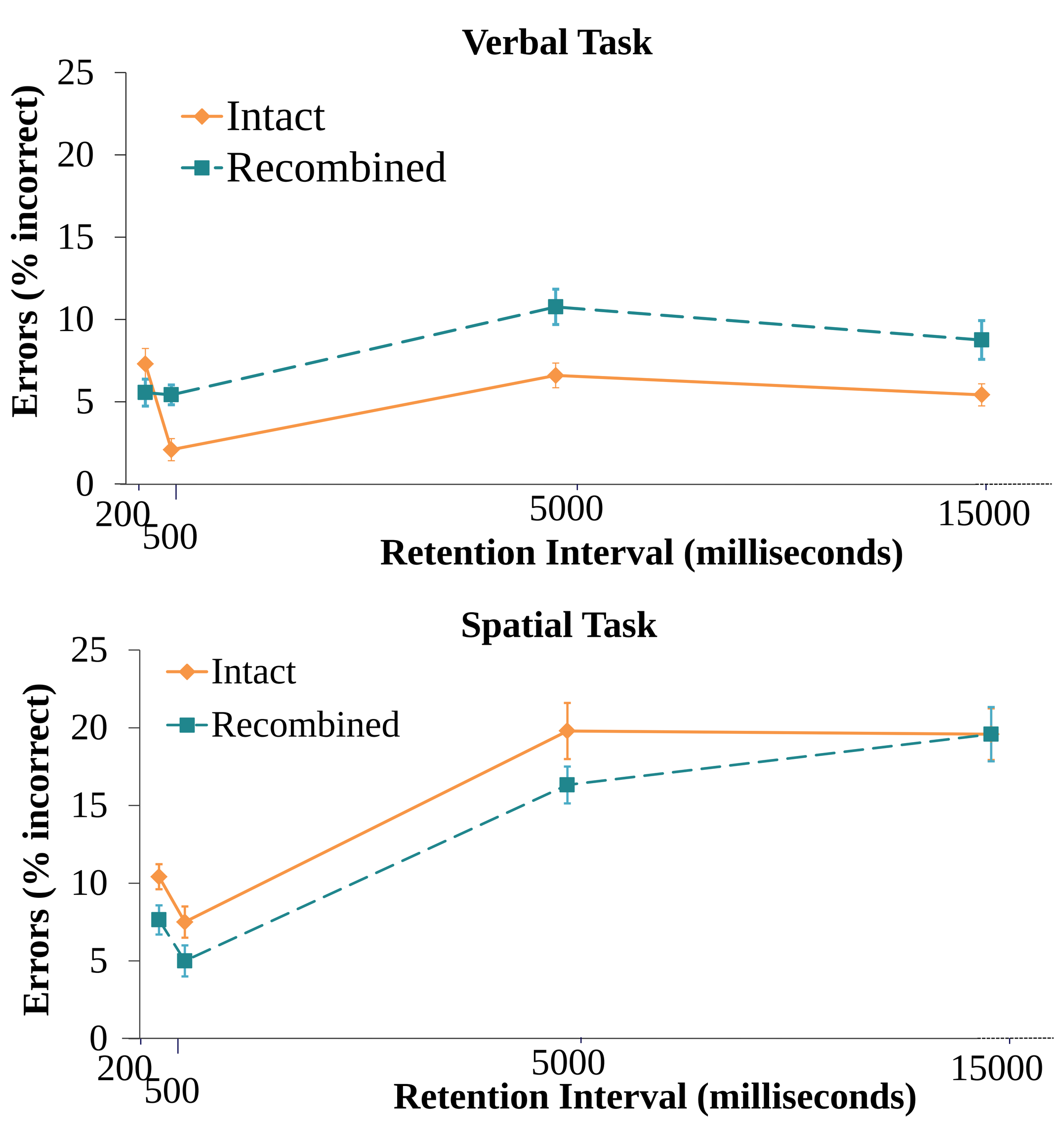

Figure 2. *Binding as a function of attended feature and retention interval. Bars represent one standard error of the mean.*

Error Analysis (% incorrect; N = 24): A 2 (memory task) x 4 (retention interval) x 2 (binding) ANOVA for repeated measures indicated:

- Superior performance in the verbal task relative to the spatial task, $F\ (1, 23) = 18.30$, $MSE = 238.63$, $p < .001$ $\eta^2_p = .44$.
- No binding effect, $F\ (1, 23) = .002$, $MSE = 81.82$, $p = .96$.
- Significant main effect of retention interval, $F\ (3, 69) = 17.27$, $MSE = 97.36$, $p < .001$, $\eta^2_p = .43$[1].
- **Significant interaction between memory task and binding**, $F\ (1, 23) = 5.42$, $MSE = 88.08$, $p = .03$, $\eta^2_p = .19$.
  - No binding in the spatial task, $F\ (1, 23) = 1.58$, $MSE = 145.60$, $p = .22$.
  - Significant binding effect in the verbal task, $F\ (1, 23) = 10.22$, $MSE = 24.31$ $p < .001$, $\eta^2_p = .31$.
- Significant interaction between memory task and retention interval, $F\ (3, 69) = 7.59$, $MSE = 79.29$, $p < .001$, $\eta^2_p = .25$[2].
- No interaction between retention interval and binding, $F\ (3, 69) = .84$, $MSE = 77.87$, $p = .48$
- No three-way interaction between factors, $F\ (3, 69) = .59$, $MSE = 84.83$, $p = .63$

Footnotes

[1]The main effect of retention interval was characterized by linear [$F\ (1, 23) = 28.58$, $MSE = 106.57$, $p < .001$, $\eta^2_p = .56$]; and cubic [$F\ (1, 23) = 19.56$, $MSE = 93.28$, $p < .001$, $\eta^2_p = .46$] trends.

[2]Further explorations of the memory task x retention interval interaction indicated steeper memory decline in the spatial task relative to the verbal task.

- Significant main effect of retention interval in the spatial task characterized by linear and cubic trends ($ps < .05$). $F\ (3, 69) = 16.59$, $MSE = 125.40$, $p < .001$, $\eta^2_p = .42$
- Significant main effect of retention interval in the verbal task characterized by a cubic trend ($p < .05$). $F\ (3, 69) = 3.95$, $MSE = 51.25$, $p = .01$, $\eta^2_p = .15$

Discussion

- The data replicate Campo et al.'s (2010) binding asymmetry: We observed a binding effect (superior performance for intact relative to recombined probes) in the verbal task, but not the spatial task.
- Furthermore, the binding observed in the verbal task was relatively long-lived, appearing to survive in memory for approximately 15 seconds post-stimulus offset. There was no evidence for binding in the spatial task.
- **Why was binding in the verbal task so robust?**
  - One possibility is that unlike Logie et al.'s (2011) study that assessed three-way bindings (between color, shape and location features), our study investigated binary associations, which may represent the default type of association in working memory (as has been argued in the perception literature: Hommel, 2004).
  - Alternatively, the longevity of binding may be a consequence of the natural reliance of verbal information on spatial location during routing cognitive operations. Future work should be addressed to these possibilities.
- Overall, our data support the **strong asymmetry hypothesis** in suggesting that memory for 'what' (letters) appears dependent on the representation of 'where' (locations: see also Olson & Marshuetz, 2005); while the pattern of filled locations can be processed independently of their contents when sufficient for task completion (Treisman & Zhang, 2006).

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