

*Short Report*

# How Can Dual-Task Working Memory Retention Limits Be Investigated?

Nelson Cowan and Candice C. Morey

*University of Missouri–Columbia*

Resource limitations are assessed by examining performance on concurrent tasks. Pitfalls in attributing dual-task conflicts to central attention rather than specific processing conflicts (Navon, 1984; Norman & Bobrow, 1975) are often underestimated. In this report, we identify a limitation in the interpretation of existing dual-task studies of working memory and describe a dual-task procedure that may be the first to assess concurrent-retention costs fairly. Our results support claims of a central capacity (e.g., Baddeley, 2001; Cowan, 2001) and challenge evidence for certain task-specific limits.

In dual-task procedures for studying working memory, two stimulus sets are presented in succession, to be retained concurrently, and memory for one or both sets is tested. Concurrent-retention costs are decrements in memory performance on one set caused by the need to retain the other set concurrently. Concurrent-retention costs are larger when the two sets share many features (e.g., two spatial arrays or two verbal lists) than when they share few features (e.g., one spatial array and one verbal list; Baddeley & Hitch, 1974; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002; Fougny & Marois, 2006). Does this mean that working memory storage is largely domain-specific? Perhaps not.

Although the theoretically relevant demand in dual-task studies of working memory is concurrent retention in two tasks, performance also could suffer from the inevitable overlap between retention in one task and encoding or responding in the other task. Set 2 encoding occurs in the presence of Set 1 retention, and responding to whichever set is tested first suffers from concurrent retention of the other set (which, in turn, suffers from response interference). If encoding or responding depends on the same resource as retention, dual-task conflicts are not solely due to the difficulty of concurrent retention. We sought to

isolate effects of dual retention without any possible contribution of conflicts with encoding or responding, and to assess whether the effects of dual-task retention depend on intertask similarity.

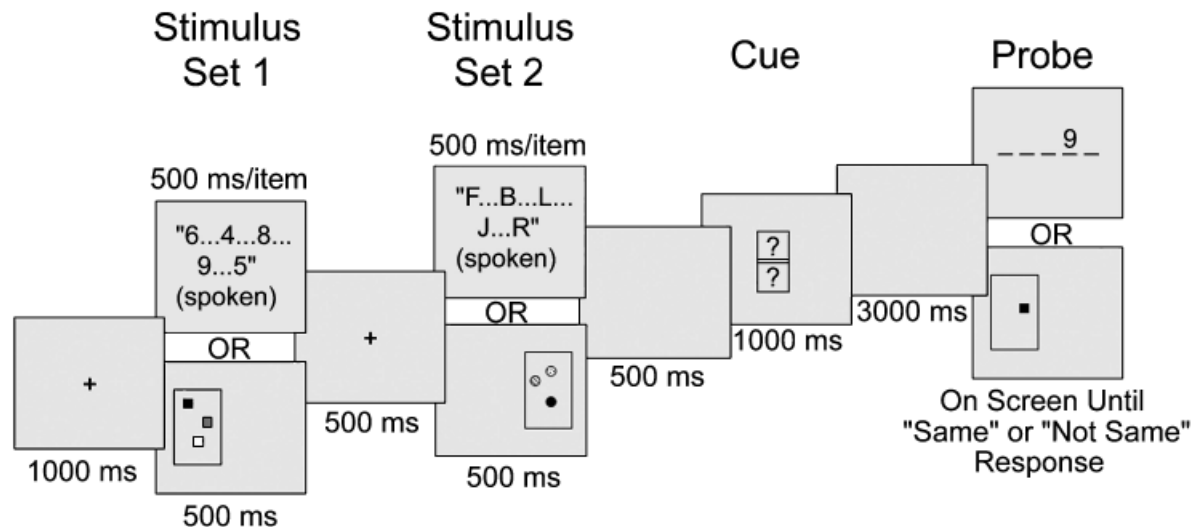
Because we collected only one response per trial, the overlap between responding and retention was eliminated. A more difficult problem was the overlap between Task 2 encoding and Task 1 retention. Our solution was to present four events on every trial in which two stimulus sets were included: Stimulus Set 1; Stimulus Set 2; a postcue to retain Set 1 only, Set 2 only, or both sets; and a memory test on one retained set. With this procedure, demands during encoding and responding are identical on trials with two stimulus sets when the postcue instruction is to retain a single set and when the postcue instruction is to retain both sets.

## METHOD

Twenty-four undergraduates learned to repeat the word *the* twice per second during encoding and retention to prevent rehearsal (Baddeley, 1986). They then completed 128 dual-task trials mixed with 48 single-task trials. On dual-task trials (Fig. 1), they received two verbal or two visual stimulus sets, or one of each. Verbal sets were lists of five letters from the superset *B, F, H, J, L, N, Q, R,* and *X* (female voice) or five digits from the superset *1, 2, 3, 4, 5, 6, 7, 8,* and *9* (male voice). Verbal stimuli were presented at a rate of 2 items/s. Visual sets were arrays of three small squares whose colors were taken from the superset *cyan, green, red, white,* and *purple*, presented to the left of fixation (for size parameters, see Morey & Cowan, 2004), or three small discs whose colors were taken from the superset *lime, magenta, black, yellow,* and *blue*, presented to the right of fixation. Visual stimuli were presented for 500 ms. Items were drawn without replacement on a trial. When the two sets on a trial were in the same domain, they came from different supersets.

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Address correspondence to Nelson Cowan, Department of Psychological Sciences, University of Missouri, 18 McAlester Hall, Columbia, MO 65211, e-mail: CowanN@missouri.edu.



**Fig. 1.** Illustration of an experimental procedure designed to isolate dual-task conflicts occurring during dual retention, as opposed to during encoding or responding. Shading of the small squares and circles represents variation in color. A spoken or visual first stimulus set is combined with a spoken or visual second set. If both sets are spoken, they differ in voice (male vs. female) and item category (digits vs. letters); if both are visual, they differ in the side of fixation (left vs. right) and type of object (squares vs. circles). The postcue (i.e., the cue presented after the memoranda) indicates the need to retain the first set (top question mark), the second set (bottom question mark), or, as shown here, both sets (two question marks; dual-retention trials). Only the processes after the cue differ between single- and dual-retention trials, and only those processes are exclusively relevant to dual-task retention.

At the end of each trial, a probe stimulus was presented, with a particular sequential position (verbal stimuli) or spatial location (visual stimuli) indicated. The participant indicated by key press if that item had appeared in that position during encoding. The results were scored using a  $k$  measure of capacity, correcting for guessing (Cowan, 2001):  $k = \text{set size} \times [p(\text{hits}) - p(\text{false alarms})]$ .

## RESULTS

Conflicts between two stimulus sets in the same domain (visual or verbal) were larger than conflicts between a visual and a verbal set. However, this additional conflict was related to encoding. For trials with only one stimulus set, the value of  $k$  was 2.96 items (visual: 2.20; auditory: 3.72). For a stimulus set in the presence of a second set of the opposite type (e.g., a visual set in the presence of a verbal set),  $k$  was 2.85 when the postcue indicated that only one set was to be retained and 2.38 when both sets were to be retained. For a stimulus set in the presence of another of the same type (e.g., one visual set in the presence of another visual set),  $k$  was 2.31 when only one set was to be retained and 1.68 when both sets were to be retained. The within-subjects 95% confidence for each mean (Loftus & Masson, 1994) was  $\pm 0.32$ . In an analysis of variance with five conditions (single set; two sets of opposite types, with one or two sets postcued; and two sets of the same type, with one or two sets postcued), the effect of condition was significant,  $F(4, 92) = 19.77$ ,  $p < .01$ ,  $\eta^2 = .46$ . All means differed significantly (Newman-Keuls tests,  $p < .05$ ), except for two inconsequential ones (2.96 vs. 2.85; 2.38 vs. 2.31).

The cost of encoding and retaining a second set, compared with a single set, was larger if the two sets were similar, 1.28 items (2.96 – 1.68), than if they differed in domain, 0.58 items (2.96 – 2.38),  $t(23) = 3.55$ ,  $p < .01$ ,  $d = 0.93$ . However, this domain-specificity of interference stemmed from demands of encoding (perhaps a limit on how many similar items could be included; cf. Woodman & Vogel, 2005). The domain-specificity of interference disappeared if we instead compared memory on trials in which two sets were encoded and the postcue called for retention of only one of them with memory on trials in which two sets were encoded and the postcue called for retention of both sets. Thus, there was no interaction between the untested-set domain (same as vs. different from the probed domain) and the load (one vs. two sets),  $F(1, 23) < 1$ . For visual probes, the cost ( $\pm 95\%$  confidence) of retaining another visual set was  $0.61 \pm 0.45$  items, closely comparable to the cost of retaining a verbal set along with the visual set,  $0.58 \pm 0.38$  items. For verbal probes, there was an insignificant ( $t < 1$ ) trend (both sets verbal:  $0.65 \pm 0.55$  items; other set visual:  $0.36 \pm 0.36$  items). There was a significant cost no matter whether the probed set was presented first ( $0.52 \pm 0.36$  items) or second ( $0.67 \pm 0.40$  items).

## CONCLUSION

Although we observed more conflict between two memory sets of the same domain than between two memory sets of different domains (visual and verbal), the additional conflict was between encoding a second set and retaining the first, and was not due to dual-set retention. Our research indicates that there is a central

storage component that encompasses the verbal and visual domains. New techniques are needed to investigate working memory while controlling encoding and responding conflicts.

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#### REFERENCES

- Baddeley, A.D. (1986). *Working memory*. Oxford, England: Clarendon Press.
- Baddeley, A.D. (2001). The magic number and the episodic buffer. *Behavioral and Brain Sciences*, *24*, 117–118.
- Baddeley, A.D., & Hitch, G.J. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic Press.
- Cocchini, G., Logie, R.H., Della Sala, S., MacPherson, S.E., & Baddeley, A.D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory & Cognition*, *30*, 1086–1095.
- Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity [Target article and commentaries]. *Behavioral and Brain Sciences*, *24*, 87–185.
- Fougnie, D., & Marois, R. (2006). Distinct capacity limits for attention and working memory: Evidence from attentive tracking and visual working memory paradigms. *Psychological Science*, *17*, 526–534.
- Loftus, G.R., & Masson, M.E.J. (1994). Using confidence intervals in within-subjects designs. *Psychonomic Bulletin & Review*, *1*, 476–490.
- Morey, C.C., & Cowan, N. (2004). When visual and verbal memories compete: Evidence of cross-domain limits in working memory. *Psychonomic Bulletin & Review*, *11*, 296–301.
- Navon, D. (1984). Resources—a theoretical soup stone? *Psychological Review*, *91*, 216–234.
- Norman, D.A., & Bobrow, D.G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, *7*, 44–64.
- Woodman, G.F., & Vogel, E.K. (2005). Fractionating working memory: Consolidation and maintenance are independent processes. *Psychological Science*, *16*, 106–113.

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