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

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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. We identify a problem 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 working memory task procedures, 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; Fougnie & Marois, 2006). Does this mean that working memory storage is largely domain-specific? Perhaps not.

Dual-task demands concern us. Although the theoretically-relevant demand 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 from 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 it depends on inter-task 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: 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 single- and dual-retention trials.

Twenty-four undergraduates learned to repeat the word “the” at a 2/s rate during encoding and retention to prevent rehearsal (Baddeley, 1986) and then completed 128 dual-task trials mixed with 48 single-task trials. On dual-task trials (Figure 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,X* (female voice) or five digits from the superset *1,2,3,4,5,6,7,8,9*

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(male voice), at 2 items/s. Visual sets were arrays of three small squares colored from the superset *cyan, green, red, white, purple*, to the left of fixation (for size parameters see Morey & Cowan, 2004), or three small discs colored from the superset *lime, magenta, black, yellow, blue*, to the right of fixation, for 500 ms. Items were drawn without replacement on a trial. When the two sets were in the same domain, they came from different supersets. The participant indicated by keypress if the probed item-in-location was correct; if not, that item had appeared elsewhere in the set. The results were scored using a K measure of capacity correcting for guessing (Cowan, 2001): K = set size * [p(hits) - p(false alarms)].

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, K=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=2.85 when the postcue indicated that only one set was to be retained, versus K=2.38 when both 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), K=2.31 when only one set was to be retained, versus K=1.68 when both were to be retained. Within-subject 95% confidence for each mean (Loftus & Masson, 1994) was ± 0.32. The condition effect was $F(4, 92)=19.77$, $p<.01$, $\eta^2=.46$. All means differed significantly (Newman-Keuls tests, $p<.05$) except two inconsequential ones (2.96 versus 2.85; 2.38 versus 2.31).

Compared to a single task, the cost of encoding and retaining another set was larger if both 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 in how many similar items could be included; cf. Woodman & Vogel, 2005). It disappeared if we instead compared memory on trials in which two sets were encoded, but were postcued for *retention* of both sets versus only one. Thus, there was no interaction of the untested-set domain (same versus different from probed domain) with the load (1 versus 2 sets), $F(1, 23)=0.45$, $p=.51$. For visual probes, the cost (±95% confidence) of retaining another visual set was 0.61+0.45 items, closely comparable to the cost of retaining a verbal set along with the visual, 0.58+0.38 items. For verbal probes, there was an insignificant ($t<1$) trend (both sets verbal, 0.65±0.55; other set visual, 0.36±0.36). There was a cost whether the probed set was presented first (0.52+0.36 items) or second (0.67+0.40 items).

Although we observed more conflict between two memory sets of the same domain than between visual and verbal sets, the additional conflict was between encoding a second set and retaining the first, not dual-set retention. Our research points to 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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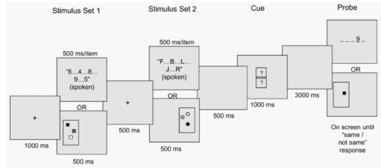

Figure 1.
Procedure in an experiment designed to isolate dual-task conflicts occurring during dual retention, as opposed to conflicts during encoding or responding. Shades of small squares and circles represent different colors. A spoken or visual first stimulus set is combined with a spoken or visual second set. If both sets are spoken, they differ in voice (male versus female) and item category (digits versus letters); if both are visual, they differ in the side of fixation (left versus right) and type of object (squares versus circles). The cue can indicate the need to retain the first set (top question mark), second set (bottom question mark) or, as in the illustration, both sets (two question marks). Only the processes after the cue differ between single- and dual-retention trials, and only those processes are exclusively relevant to dual-task retention.