WORKING MEMORY CONSTRAINTS ON SYMBOLIC COMPARISON

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Abstract

In this study, 54 participants performed binary comparisons involving learned symbolic stimuli from an artificially induced linear ordering (i.e., the names of six imaginary individuals assumed to differ in height). On half of the comparison trials, they also performed one of three working memory tasks assumed to tap the resources of the phonological loop, the visual-spatial sketchpad, or the central executive components of Baddeley and Hitch's (1974) model. Perhaps surprisingly, both concurrent articulatory suppression and spatial tapping did not affect comparison RTs very much, although spatial tapping did result in an enhancement of the symbolic distance effect in the accuracy measures. On the other hand, concurrent random letter generation had a dramatic effect on both RT and accuracy and resulted in enhancements of the distance, end, and semantic congruity effects. These results call into question the automaticity of the symbolic comparison process and also imply that at least some part of it involves spatial processing.

Typically, the attempts made by symbolic comparison researchers at differentiating between the various types of available models of the symbolic comparison process have involved determining the extent to which each model can account for various kinds of empirical findings surrounding the three major symbolic comparison response time effects (i.e., the *distance*, *end*, and *semantic congruity* effects; for reviews Leth-Steensen & Marley, 2000; Petrusic, 1992). The work reported here will depart markedly from this approach by attempting to examine more closely the nature of both the cognitive processing that is occurring and the types of mental representations that are being used when making symbolic comparisons. The approach used here will be to determine the way in which various types of secondary tasks, currently popular within working memory research paradigms (Baddeley & Hitch, 1974), interfere with symbolic comparison performance in terms of both the speed and accuracy of responding (for some closely related work see Dean, Dewhurst, Morris, & Whittaker, 2005, and De Rammaleare and Vandierendonck, 2003).

Method

Participants. Fifty-four Introductory Psychology students from Carleton University with normal or corrected-to-normal vision participated (individually) in a 90-minute session for course credit.

Stimuli and Apparatus. The stimuli and apparatus used were the same as for Shaki and Leth-Steensen (2009; see that paper in this same ISP Proceedings) and will not be repeated here.

Procedure. The procedure for the learning and test phases of the primary symbolic comparison task was essentially identical to that described in Shaki and Leth-Steensen (2009) and will also not be repeated here except to note that the comparison responses in this study were always made with the index and middle fingers of the left hand (i.e., not with the left- and right-hand index fingers as in Shaki & Leth-Steensen, 2009).

In two of the four test phase blocks in this study, participants were required to perform one of three working memory secondary tasks (see below) at the same time as they made the comparison responses. Half of the participants performed the two blocks of comparison trials plus the secondary task first and the other half performed them last. Each participant was given a small set of initial practice comparison trials with the secondary task. For the primary symbolic comparison task, participants were asked to try to be accurate in each decision without taking too much time to respond.

Three working memory secondary tasks were used in this study. In the articulatory suppression condition (n = 18), participants were instructed to repeat aloud four letters (i.e., F, J, N, and W) at a constant rate of about 2-3 digits per second. Concurrent performance of such a task is presumed to interfere with short-term verbal/phonological processing and rehearsal mechanisms. In the spatial tapping condition (n = 20), participants were instructed to tap out a sequence of four number keys (1, 2, 6, and 8, respectively, on the numeric keypad) with their right index finger in a counter-clockwise fashion at a constant rate of about 2-3 numbers per second. Concurrent performance of this task is presumed to interfere with short-term visual-spatial processing and rehearsal mechanisms. In the random letter generation condition (n = 16), participants were instructed to repeat aloud the same sequence of four letters used in the articulatory suppression condition, at the same constant rate, but in a random order (e.g., F, N, W, W, J, etc.). Concurrent performance of such a task is presumed invoke highly demanding central-executive-based attentional interference.

Results

A number of statistical analyses were performed on the response time and response accuracy data. First, both the median correct response times and the mean proportion correct for each pair under each form of the comparative instruction in each working memory condition were obtained for each participant. For analyses of the overall distance effects, these data were then averaged over all of the pairs at each level of split. Otherwise, the Split 1 data were directly subjected to separate analyses. Within each analysis separately, any response time values that were either missing or more than 3 SDs above the mean of the corresponding cell of the design were replaced (i.e., 2 and 14 RT values in the distance and Split 1 analyses, respectively). All analyses of the proportion correct measures were conducted using arcsine-transformed proportions even though it is the untransformed measures that are presented graphically.

Distance Effects

A repeated measures ANOVA on each secondary task group's data was performed that included level of split (i.e., 1, 2, 3, 4, and 5), instruction type (i.e., "Shorter?" and "Taller"), and secondary task condition (control and secondary task) as the relevant independent variables. The response time and response accuracy data corresponding to these analyses are shown Figures 1 and 2, respectively.

Response Times. For the articulatory suppression group, the main effect of the secondary task condition was only marginally significant, $F(1, 17) = 3.92$, $.05 < p < .10$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F(4, 68) = 30.05$, $p < .001$. The interaction of secondary task condition and split was not significant, $F(4, 68) = 0.68$, $p > .50$.

For the spatial tapping group, the main effect of the secondary task condition was not significant, $F(1, 19) = 2.11$, $p > .10$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F(4, 76) = 68.22$, $p < .001$. The interaction of secondary task condition and split was not significant, $F(4, 76) = 0.27$, $p > .50$.

For the random letter generation group, the main effect of the secondary task condition was significant, $F(1, 15) = 43.26$, $p < .001$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F(4, 60) = 15.11$, $p < .001$. The overall interaction of secondary task condition and split was not significant, $F(4, 60) = 1.89$, $p > .10$. Nonetheless, the linear trend of the Split × Secondary Task interaction was significant, $F(1, 15) = 4.85$, $p < .05$, indicating that the slope of the distance effect was significantly steeper in the secondary task condition (see Figure 1).

Accuracy. For the articulatory suppression group, the main effect of the secondary task condition was only marginally significant, $F(1, 17) = 3.76$, $.05 < p < .10$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F(4, 68) = 18.76$, $p < .001$. The interaction of secondary task condition and split was not significant, $F(4, 68) = 1.60$, $p > .10$.

For the spatial tapping group, the main effect of the secondary task condition was significant, $F(1, 19) = 11.40$, $p < .01$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F\ (4, 76) = 25.93$, $p < .001$. The overall interaction of secondary task condition and split was not significant, $F(4, 76) = 1.63$, $p > .10$. Nonetheless, the linear trend of the Split × Secondary Task interaction was significant, $F(1, 19) = 10.72$, $p < .01$, indicating that the slope of the distance effect in accuracy was significantly steeper in the secondary task condition (see Figure 2).

For the random letter generation group, the main effect of the secondary task condition was significant, $F(1, 15) = 12.40$, $p < .01$. The presence of a substantial distance effect was marked by a significant overall main effect of split, $F\ (4, 60) = 9.09$, $p < .01$. The interaction of secondary task condition and split was only marginally significant, $F(4, 60) = 2.21$, $.05 < p < .10$, but the linear trend of the Split × Secondary Task interaction was significant, $F(1, 15) = 7.13$, $p < .05$, indicating that the slope of the distance effect in accuracy was significantly steeper in the secondary task condition (see Figure 2).

End and Semantic Congruity Effects: Split 1 Data

Next, a repeated measures ANOVA on each secondary task group's data was performed that included pair (i.e., [1, 2], [2, 3], [3, 4], [4, 5], and [5, 6]), instruction type, and secondary task condition (control and secondary task) as the relevant independent variables. The data for the response time analysis are shown Figures 3 and 4, respectively (note that no interactions involving the secondary tasks were present in the corresponding accuracy data).

Response Times. For the articulatory suppression group, the main effect of the secondary task condition was not significant, $F(1, 17) = 2.93$, $p > .10$. The presence of an end effect was marked by a significant overall main effect of pair, $F(4, 68) = 24.93$, $p < .001$. The Pair × Secondary Task Condition interaction was not significant, $F(4, 68) = 0.65$, $p > .50$. The presence of a semantic congruity effect was marked by a significant interaction of the pair and instruction factors, $F(4, 68) = 3.36$, $p < .05$. The Pair × Instruction × Secondary Task Condition interaction was not significant, $F(4, 68) = 0.71$, $p > .50$.

For the spatial tapping group, the main effect of the secondary task condition was not significant, $F(1, 19) = 0.59$, $p > .10$. The presence of an end effect was marked by a significant overall main effect of pair, $F(4, 76) = 26.21$, $p < .001$. The Pair × Secondary Task Condition interaction was not significant, $F(4, 76) = 0.87$, $p > .10$. The presence of a semantic congruity effect was marked by a significant interaction of the pair and instruction factors, $F(4, 76) = 7.53$, $p < .001$. The Pair × Instruction × Secondary Task Condition interaction was not significant, $F(4, 76) = 0.05$, $p > .50$.

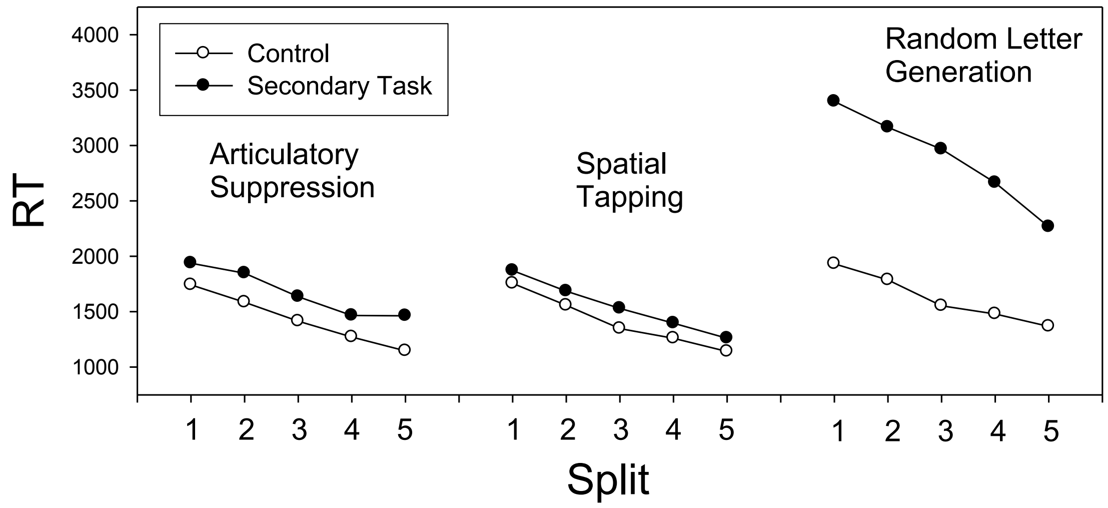

Figure 1. Average median correct response times (RT) at each level of split for each secondary task condition.

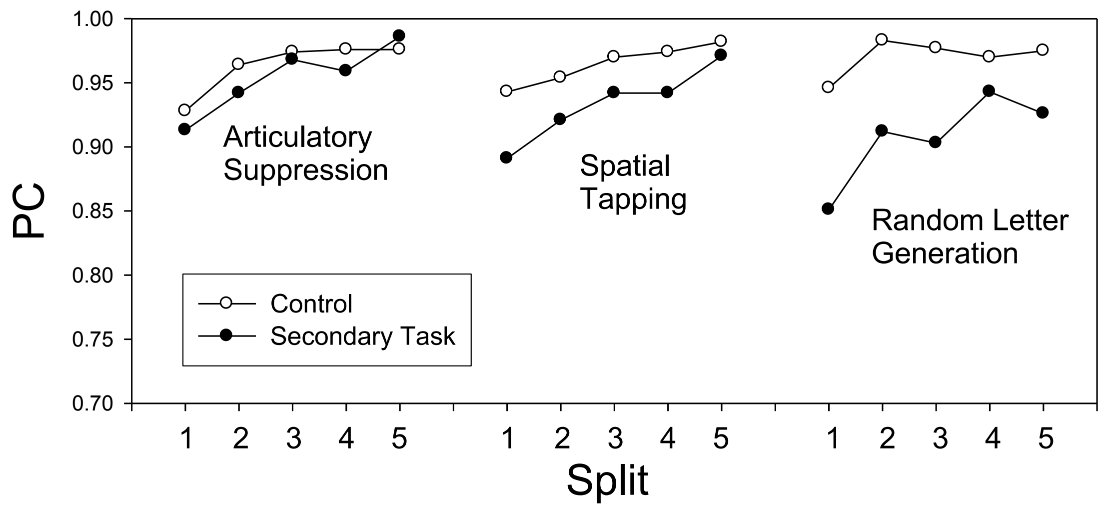

Figure 2. Average proportion correct (PC) at each level of split for each secondary task condition.

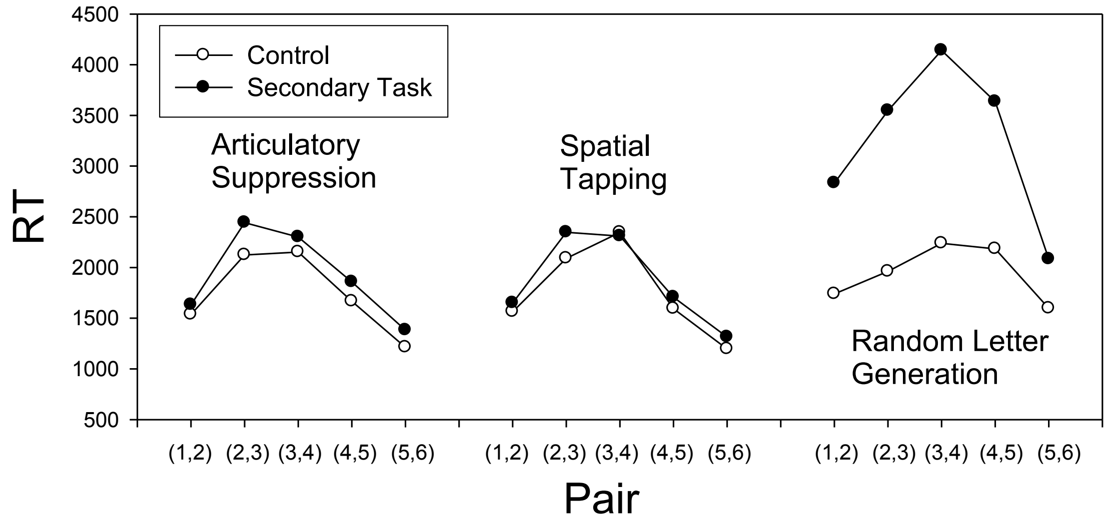

Figure 3. Average median correct response times (RT) for each Split 1 pair for each secondary task condition.

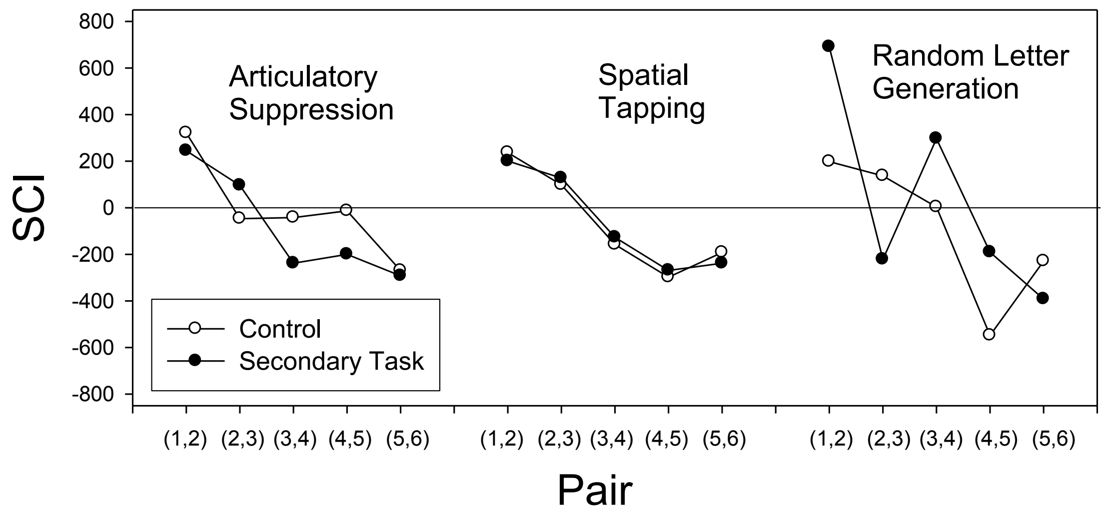

Figure 4. Semantic congruity index (SCI) representing the difference between the average median correct response times for each Split 1 pair under each form of the comparative instruction (i.e., Larger? – Smaller?) for each secondary task condition.

For the random letter generation group, the main effect of the secondary task condition was significant, $F(1, 15) = 30.58$, $p < .001$. The presence of an end effect was marked by a significant overall main effect of pair, $F(4, 60) = 14.24$, $p < .001$. The Pair × Secondary Task Condition interaction was significant here, $F(4, 60) = 6.11$, $p < .001$. The presence of a semantic congruity effect in these data was marked by a marginally significant interaction of the pair and instruction factors, $F(4, 60) = 2.45$, $.05 < p < .10$. The Pair × Instruction × Secondary Task Condition interaction was not significant, $F(4, 60) = 0.86$, $p > .10$. Nonetheless, it must be noted that if the latter analysis is restricted to just the two end-term pairs, a significant Pair × Instruction × Secondary Task Condition is indeed present, $F(1, 15) = 4.89$, $p < .05$.

Discussion

The present results demonstrate that that symbolic comparison response times become dramatically slowed and all three symbolic comparison response time effects become enhanced under interference from a concurrent random letter generation task. Clearly, one major effect of such a secondary task is to slow down the rate of decisional processing in the primary comparison task indicating that such processing does not, in fact, run off automatically. Most likely, it is the case that the process of retrieving/scheduling the random generation responses is interfering with the retrieval of the magnitude information associated with the symbolic items. In addition, distance effects in accuracy were significantly enhanced under concurrent performance of either random letter generation or the spatial tapping indicating that the quality of the information being used by the decision process is affected by both of these secondary tasks.

The latter result provides some evidence that spatial processing indeed has some role to play in the symbolic comparison decision process. Interestingly, though, the fact that spatial tapping interference does not seem to affect the timing of such decisional processing seems to be at odds with the notion that participants are representing symbolic magnitudes within such a task by constructing a spatially based array (and even more so with the notion that they might be performing comparisons by scanning such an array). Finally, the relatively minor interfering effects of concurrent articulatory suppression that were observed here suggest that serial verbal rehearsal of the ordering does not seem to have much of a role in the decision process itself (i.e., once the ordering has been learned) in stark contrast to the, often unsolicited, verbal reports of the participants themselves.

References

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