Irrelevant Tapping and the Acoustic Confusion Effect: The Effect of Spatial Complexity

Katherine Guérard[1], Annie Jalbert[2], Ian Neath[2], Aimée M. Surprenant[2], & Tamra J. Bireta[3]

RUNNING HEAD: Tapping and the acoustic confusion effect

[1]Université Laval

[2]Memorial University of Newfoundland

[3]The College of New Jersey

Correspondence:
Katherine Guérard
École de psychologie
Université Laval
Québec
G1V 0A6
Canada
Tel. +(418) 656-2131 Ext. 4305
Fax +(418) 656-3646
Email: katherine.guerard.1@ulaval.ca

Abstract

When items in a to-be-remembered list sound similar, recall performance is worse than when items are acoustically distinct, what is known as the acoustic confusion effect (ACE). When participants are asked to tap a syncopated rhythm during list presentation, the difference between the acoustically similar and dissimilar conditions is abolished; however simple temporal and simple spatial tapping tasks have no effect. The objective of the present study is to examine whether spatial complexity is a property of the tapping task that interferes with the ACE. Participants were asked to tap a simple (Experiment 1) or a complex spatial pattern (Experiment 2) at a regular pace during a verbal serial recall task in which acoustic similarity was manipulated. The results showed that simple spatial tapping had no effect on the ACE whereas complex spatial tapping significantly reduced the effect. Implications for three theories of memory are discussed.

Irrelevant Tapping and the Acoustic Confusion Effect: The Effect of Spatial Complexity

The acoustic confusion effect (ACE; also called the phonological similarity effect) refers to the finding that similar-sounding letters and words are more poorly recalled than dissimilar-sounding items (Baddeley, 1966; Conrad, 1964; Murray, 1967). One common technique to study this phenomenon is to examine what factors interact with the effect. Both the articulation of irrelevant tokens (articulatory suppression; see Baddeley, Lewis, & Vallar, 1984; Coltheart, 1993; Larsen & Baddeley, 2003; Longoni, Richardson, & Aiello, 1993), and hearing irrelevant verbal stimuli (irrelevant speech; see Colle & Welsh, 1976; Larsen, Baddeley, & Andrade, 2000; Surprenant, Neath, Bireta, & Allbritton, 2008) during list presentation of a typical verbal serial recall task reduce or even abolish the ACE. Although important theoretically, it is not surprising that irrelevant verbal material should interfere with the to-be-remembered verbal material. One perhaps less expected finding is that at least one non-verbal manipulation also interacts with the ACE: when participants are asked to tap out a syncopated pattern during list presentation, the difference in recall of the similar- and dissimilar-sounding items is reduced or even eliminated (Larsen & Baddeley, 2003; Saito, 1993, 1994; Surprenant et al., 2008). The purpose of the present series of experiments is to examine a previously overlooked characteristic of the tapping task and determine whether it also interacts with the ACE.

Tapping involves both a temporal dimension and a spatial dimension, but most of the research so far has focused on comparing the effects of simple versus complex temporal tapping. For example, Saito (1993) had participants press a single button either once every 320 ms or press the same button in a syncopated pattern as follows: 400 ms, 400 ms, 200 ms, 400 ms, 200 ms. The particular pattern of tapping was indicated by a beep, and in the control condition, participants did not tap at all but still heard the beeps. Syncopated tapping eliminated the ACE almost entirely, whereas simple tapping had no effect.

Larsen and Baddeley (2003) replicated this general pattern: regular tapping of a single key had no effect on the ACE whereas syncopated tapping of a single key abolished the effect. Similarly, Saito (1997) replicated the null result of simple tapping (tapping a desk with the index finger) and Surprenant et al. (2008; see also Saito, 1994) replicated the positive result that syncopated tapping of a single key had the same effect on the ACE as did irrelevant speech.[1]

Unlike other studies, Larsen and Baddeley (2003; Experiment 3) included a spatial manipulation in their simple tapping task: They asked participants to tap the keys on the numeric keypad in a clockwise loop but at temporally regular intervals. This manipulation had no effect on the ACE. To our knowledge, no other researchers have investigated whether complex spatial tapping (with a simple, regular temporal pattern, but a complex spatial pattern) disrupts the ACE. This issue is important for the possible theoretical interpretations. If complex spatial tapping does not affect the ACE, then it suggests that the key factor underlying disruption of the ACE by tapping is temporal. However, if complex spatial tapping does affect the ACE, then it suggests that more general-purpose mechanisms may be responsible.

Is there any reason to suspect that spatial tapping should function like temporal tapping? In a somewhat different literature, researchers typically use simple spatial tapping under the assumption that it interferes with the processing of spatial information (see Andrade, Kemps, Werniers, May, & Szmalec, 2002; Guérard & Tremblay, 2008; Kemps, 2001; Meiser & Klauer,

[1] Henson, Hartley, Burgess, Hitch, and Flude (2003) compared simple and syncopated tapping, using only a single spatial location, but with a probe design. However, their results are difficult to interpret, as some of the data suffered from a limitation in range (see their discussion on p. 1330).

1999; Zimmer, Speiser, & Seidler, 2003). Indeed, spatial tapping is generally more disruptive for spatial memory than for verbal (e.g., see Guérard & Tremblay, 2008) or visual memory (Klauer & Zhao, 2004; Zimmer et al., 2003). However, spatial tapping does affect verbal memory, and Jones, Farrand, Stuart, and Morris (1995) found equivalent impairment of verbal and spatial memory under certain conditions.

On the other hand, Larsen and Baddeley (2003, Experiment 3) found that a simple tapping task with regular timing (and thus a simple temporal component) in which participants tapped in different spatial locations did not affect the ACE. Based on this pattern of results, Larsen and Baddeley suggested that the tasks have different loci: Simple tapping, whether it is spatial or not, requires central executive resources, which may lead to slight reductions in overall performance levels, but which do not lead to interaction with the ACE. In contrast, syncopated tapping calls on language motor programs used in verbal serial recall. This interpretation seems to be consistent with the fact that syncopated tapping implies a variation of the temporal dimension similar to that found in natural speech rhythm. Syncopated tapping however, is also more complex than the spatial tapping tested heretofore, as evidenced by the larger interference observed with syncopated tapping on the overall level of performance (e.g., see Larsen & Baddeley, 2003).

Before concluding about the locus of the disruption caused by syncopated tapping, it is therefore essential to investigate what factors are the key to the interference in memory. The objective of the present study is to verify whether complexity is a characteristic of the tapping tasks that interferes with the ACE. The experiments reported here examined the effects of simple (Experiment 1) and complex tapping (Experiment 2) when the temporal properties of the tapping remained constant but the spatial properties were manipulated. In all experiments, the temporal rhythm of the taps was regular: participants had to tap once every 300 ms.

Experiments 1a and 1b

The objective of Experiment 1 was to replicate earlier findings showing that simple spatial tapping does not alter the ACE (e.g., see Larsen & Baddeley, 2003, Experiment 3). Participants were asked to alternate tapping between a left and right location during item presentation, as indicated by beeps presented alternatively to the left and right ears (Experiment 1b). A control experiment (1a) had beeps playing over the headphones, but the participants were not required to tap. This experiment was conducted in order to ensure that hearing the beeps had no effect on performance, so that any effect of tapping could not be attributed to an irrelevant sound effect (e.g., see Jones & Macken, 1993).

Experiment 1a

Method

Participants. Twenty young adults from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium.

Stimuli. The stimuli were the letters F K L M R Q in the dissimilar condition and B D G P T V in the similar condition, a subset of those used by Colle and Welsh (1976). The letters were presented visually on the computer screen, in uppercase, 28 point Helvetica. A 440 Hz tone of 50 ms was used as the beeps and presented through headphones to the participants.

Design. There were three within-subjects variables: Beeps (2 levels; no beeps, beeps), acoustic similarity (2 levels; dissimilar, similar), and serial position (6 levels; 1 to 6). There were 10 trials in each of the four conditions (no beeps dissimilar, no beeps similar, beeps dissimilar, beeps similar). The order of the trials was randomly determined for each subject.

Procedure. Participants were tested individually. They were first instructed that their task was to recall the order in which they saw six letters. The letters were presented at a rate of one every 500 ms (500 ms on/0 ms off). On half of the trials, a total of 15 beeps were played at a rhythm of one per 300 ms. For half of the participants, the first beep was presented to the left ear, and the remaining beeps alternated right, left, and so on. For the other half of the participants, the first beep was presented to the right ear, and the remaining beeps alternated left, right, and so on. The first five beeps were played prior to the beginning of list presentation, and the last beep coincided with the end of the list.

After the presentation of the list, twelve buttons appeared labelled, in alphabetical order, with the twelve letters used for similar and dissimilar trials. Participants were asked to click on the buttons to recreate the order in which the letters had been shown (i.e., strict serial reconstruction of order). They were not allowed to change an answer once they had clicked on a button. Participants were informed they could take rest breaks at any point. An experimenter remained in the room to ensure compliance with the instructions.

Results and Discussion

A response was scored as correct if the letter was recalled in the same serial position in which it had been presented. Figure 1 shows a typical ACE with similar sounding letters more poorly recalled (0.503) than dissimilar sounding letters (0.739). The beeps had no effect on performance: Recall in the quiet condition (0.629) did not differ from recall in the beeps condition (0.613). These observations were confirmed by a 2 (beeps) x 2 (similarity) x 6 (serial position) repeated measures analysis of variance (ANOVA) carried out on the proportion of correct responses. In all analyses, the .05 level of significance was adopted and the Greenhouse-Geisser correction was applied when sphericity was violated. The analysis showed that the main effects of similarity, $F(1, 19) = 32.87$, $MSE = 0.20$, $\eta^2_p = .63$, $B = 1.00$, and of serial position, $F(5, 95) = 69.11$, $MSE = 0.05$, $\eta^2_p = .78$, $B = 1.00$, were significant, but not the main effect of beeps, $F(1, 19) = 1.14$, $MSE = 0.03$, $\eta^2_p = .06$, $B = 0.17$. The interaction between similarity and serial position was significant, $F(5, 95) = 14.39$, $MSE = 0.02$, $\eta^2_p = .43$, $B = 0.45$, probably due to the fact that the ACE increased as a function of serial position. No other interactions were significant.

Experiment 1b

Experiment 1a demonstrated that the pattern of beeps needed to mark the simple spatial tapping pattern had no measurable effect on performance. Experiment 1b was identical to Experiment 1a except that participants had to press the "1" and "2" keys of the numeric keypad as directed by the beeps presented over the headphones.

Method

Participants. Forty different subjects from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium.

Stimuli. The stimuli were the same as in Experiment 1a.

Design. There were three within-subjects variables: Tapping (2 levels; no tapping, tapping), similarity (2 levels; dissimilar, similar), and serial position (6 levels; 1 to 6). There were 10 trials in each of the four conditions (no tapping dissimilar, no tapping similar, tapping dissimilar, tapping similar). The order of the trials was randomly determined for each participant.

Procedure. This experiment was identical to Experiment 1a, except that participants were asked to press the 1-key on the numeric keypad with their right index finger of their right hand when they heard a beep in the left ear, and to press the 2-key on the numeric keypad with their right index finger when they heard the beep in the right ear. During all the experimental trials, the beeps were presented over the headphones. Instructions prior to the beginning of each trial indicated whether participants had to tap or not. In the tapping trials, the instruction "Prepare to tap" was written on the screen. In the no tapping trials, the instruction "No tapping" was visible. In order to ensure that participants fully understood the tapping instructions, there was a short training phase prior to the experiment proper. There were 6 trials in which participants had to execute the tapping task alone: in each trial, 15 beeps were presented throughout the headphones but no items appeared on the screen. Then, there were 4 trials in which participants were asked to recall a random permutation of the digits 1-6 while tapping. During this practice phase, the experimenter carefully explained the procedure and ensured that by the end, the participants were following the instructions.

Results and Discussion

Figure 1 shows once again that acoustic similarity impaired performance, with worse recall of similar (0.471) than dissimilar (0.708) items. More importantly, although tapping had a slight effect on overall performance (0.626 in no tapping vs. 0.553 with tapping), it had no effect on the magnitude of the ACE. These observations were supported by a 2 (tapping) x 2 (similarity) x 6 (serial position) repeated measures ANOVA which revealed that the main effects of tapping, $F(1, 39) = 21.62$, $MSE = 0.06$, $\eta^2_p = .36$, $B = 1.00$, of similarity, $F(1, 39) = 146.54$, $MSE = 0.09$, $\eta^2_p = .79$, $B = 1.00$, and of serial position, $F(5, 195) = 102.81$, $MSE = 0.07$, $\eta^2_p = .73$, $B = 1.00$, were significant. The interaction between similarity and serial position was also significant, $F(5, 195) = 20.21$, $MSE = 0.03$, $\eta^2_p = .34$, $B = 1.00$. Importantly, the interaction between tapping and similarity was not significant, $F(1, 39) = 2.37$, $MSE = 0.04$, $\eta^2_p = .06$, $B = 0.32$, suggesting that tapping did not alter the size of the ACE. No other interactions were significant. In line with the results of Larsen and Baddeley (2003), simple spatial tapping with a regular temporal component slightly impaired overall performance, but had no effect of the ACE.

Experiments 2a and 2b

Several studies have shown that simple temporal tapping does not affect the magnitude of the ACE whereas complex temporal tapping does. Experiment 1b showed that simple spatial tapping acts like simple temporal tapping: overall performance may be slightly reduced, but there is no differential effect on the ACE (see Larsen & Baddeley, 2003). In Experiment 2, participants were asked to tap a more complex spatial pattern derived from the complex temporal tapping task used by Saito (1994; see also Surprenant et al., 2008). Instead of manipulating the length of the interval separating each tap, we varied the locations of the tap: Participants alternated between the right and left keys in a regular temporal pattern, but in a complex spatial pattern (Experiment 2b). Once again, a control experiment (2a) had beeps playing but the participants did not have to tap. This was done in order to make sure that a more complex pattern of otherwise identical beeps had no effect on performance.

Experiment 2a

Method

Participants. Twenty young adults from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium.

Stimuli. The stimuli were identical to those in Experiment 1a.

Design and procedure. The design and procedure were identical to Experiment 1a except that the pattern played throughout the headphones was different. For half of the participants, the pattern was left-right-left-left-right which then repeated, so that one location repeated itself every four beeps. The other half of the participants had the same pattern but started with the beep in the right ear (which was the location that repeated itself).

Results and Discussion

As in Experiment 1a, there was a typical ACE with similar sounding letters more poorly recalled (0.502) than dissimilar sounding letters (0.830). The beeps had no effect on performance: Recall in the quiet condition (0.667) did not differ from recall in the beeps condition (0.665). These observations were supported by a 2 (beeps) x 2 (similarity) x 6 (serial position) repeated measures ANOVA which revealed that the main effects of similarity, $F(1, 19) = 142.24$, $MSE = 0.09$, $\eta^2_p = .88$, $B = 1.00$, and of serial position, $F(5, 95) = 53.08$, $MSE = 0.05$, $\eta^2_p = .74$, $B = 1.00$, were significant, but not the main effect of beeps, $F < 1$. The interaction between similarity and serial position was significant, $F(5, 95) = 15.29$, $MSE = 0.03$, $\eta^2_p = .45$, $B = 1.00$, but no other interactions were significant.

Experiment 2b

Experiment 2a demonstrated that the pattern of beeps needed to mark the complex spatial pattern had no measurable effect on performance. Experiment 2b was identical to Experiment 2a except that participants now had to tap the complex spatial pattern indicated by the beeps played over the headphones.

Method

Participants. Forty different subjects from Memorial University of Newfoundland volunteered to participate in exchange for a small honorarium.

Stimuli. The stimuli were the same as in Experiment 1b.

Design and procedure. The design and procedure were identical to Experiment 1b, that is, participants had to tap alternatively on the “1” and “2” keys of the numerical keyboard, except that they had to follow the complex spatial pattern described in Experiment 2a.

Results and Discussion

As shown in Figure 1, overall acoustic similarity impaired performance, with worse recall of similar (0.427) than dissimilar (0.619) items. Tapping had a large effect on the overall level of performance, decreasing from 0.644 in the no tapping condition to 0.402 with tapping. More importantly, complex spatial tapping reduced the magnitude of the ACE. These observations were supported by a 2 (tapping) x 2 (similarity) x 6 (serial position) repeated measures ANOVA which indicated that the main effects of tapping, $F(1, 39) = 108.49$, $MSE = 0.13$, $\eta^2_p = .74$, $B = 1.00$, of similarity, $F(1, 39) = 81.71$, $MSE = 0.11$, $\eta^2_p = .68$, $B = 1.00$, and of serial position, $F(5, 195) = 104.47$, $MSE = 0.07$, $\eta^2_p = .73$, $B = 1.00$, were significant. The significant interaction between tapping and similarity confirmed that that complex spatial tapping altered the ACE, $F(1, 39) = 11.88$, $MSE = 0.05$, $\eta^2_p = .23$, $B = 0.92$, although the main effect of similarity was still significant in the tapping condition, $F(1, 39) = 34.13$, $MSE = 0.01$, $\eta^2_p = .47$, $B = 1.00$. The interaction between similarity and serial position, $F(5, 195) = 17.57$, $MSE = 0.02$, $\eta^2_p = .31$, $B = 1.00$, as well as the three-way interaction between tapping, similarity and serial position, $F(5, 195) = 4.61$, $MSE = 0.01$, $\eta^2_p = .11$, $B = 0.97$, were significant. The interaction between tapping and serial position was not significant, $F(5, 195) = 1.54$, $MSE = 0.03$, $\eta^2_p = .04$, $B = 0.43$.

General Discussion

The objective of the present study was to determine whether spatial complexity is a characteristic of the tapping task that can affect the ACE. In line with the results of Larsen and Baddeley (2003), simple spatial tapping (with a simple temporal rhythm) had no effect on the ACE. The novel finding is that complex spatial tapping (with a simple temporal rhythm) significantly decreased the magnitude of the ACE. Manipulating spatial complexity of the tapping task while holding the temporal component constant has a similar effect on the ACE as manipulating temporal complexity of the tapping task while holding the spatial component constant. Our results add to those from a number of studies showing that a non-verbal secondary task can interfere with the processing of verbal information (Jones et al., 1995; Jones & Macken, 1993; LeCompte, Neely, & Wilson, 1997).

The most common explanation of the ACE (e.g., Baddeley et al., 1984; Coltheart, 1993; Longoni et al., 1993) invokes Baddeley's Working Memory framework (Baddeley, 1986, 2003).

Verbal information in working memory is handled by the phonological loop, which is made up of the phonological store and an articulatory rehearsal process. Auditory verbal items have direct and obligatory access to the phonological store, whereas visual verbal items have to be recoded into a phonological form before they can be represented in the phonological store. The ACE occurs due to confusion between similar sounding items in the phonological store. One prediction of this account is that the ACE will be abolished for visual but not auditory items if the articulatory rehearsal process is otherwise occupied by, for example, concurrent articulation. This prediction has been confirmed (e.g., Baddeley et al., 1984). This occurs because concurrent articulation prevents the articulatory rehearsal process from converting the visually-presented items into a phonological format.

Following Saito's (1994) suggestion, Larsen and Baddeley (2003) suggested that syncopated tapping interferes with the articulatory rehearsal process. Because of this, visually-presented verbal information is not able to enter the phonological store and therefore confusions based on how the verbal items sound do not arise. In contrast, simple temporal tapping and simple spatial tapping do not interfere with the articulatory rehearsal process. Rather, these tasks may reduce central executive resources, which would account for the absence of an interaction with the ACE but a slight decrease in overall performance.

According to this view, it is the irregular-rhythmic aspect of the task resembling that of speech that is responsible for blocking the action of the articulatory loop and reducing the ACE (Saito, 1994; Larsen & Baddeley, 2003). One hypothesis is to suppose that complex spatial tapping, like syncopated tapping, interferes with speech production or has a direct access to the phonological store. However, this causes two problems. First, there were no rhythmic irregularities in our complex spatial tapping task: participants had to tap at the same regular interval as the simple spatial tapping task. Second, if a spatial task interferes with speech production, then, the relevance of having a sub-system specialized for the processing of verbal information becomes increasingly tenuous. Indeed, why should there be a component specific for the processing of verbal information if any type of task (verbal, spatial, etc.) interferes with the functioning of this system?

Another approach is the Perceptual-Gestural view, according to which the processing of information in memory is viewed as being accomplished by peripheral processes such as general-purpose planning mechanisms and perceptual organisation (see Jones Macken, & Nicholls, 2004; Jones, Hughes, & Macken, 2006). According to this approach, the ACE occurs because acoustically similar letters disrupt the perceptual organisation of the sequence and are more prone to errors during the planning of speech. Simple spatial tapping however, although it was found to disrupt perceptual organisation (Jones et al., 1995), did not alter the ACE in Experiment 1 (see also Larsen & Baddeley, 2003). Moreover, although the model refers to *general*-purpose planning mechanisms used irrespective of the type of information, it is unclear whether complex spatial tapping require motor planning abilities also called for during verbal serial recall.

A different approach to ACE research comes from the Feature Model (Nairne, 1990; Neath, 2000). According to this model, items are represented as vectors of features, some of which represent modality specific information and some of which represent information that is independent of the modality of presentation. Retrieval is based, in part, on the relative match between a degraded cue and the undegraded representations of all likely responses, a process known as redintegration. The ACE occurs because similar-sounding items will share more features with competitors than dissimilar-sounding items and therefore, there is a decreased probability of successfully matching a cue and the correct items. The ACE is reduced or abolished when features from the irrelevant material are included in the cues reprsenting the to-be remembered letters through a process called feature adoption. When an item adopts a feature, it reduces the match between the cue and the undegraded representation, thereby increasing the chances of a mismatch. Feature adoption, then, removes the advantage that the dissimilar items formerly had over the similar items, thus reducing or eliminated the ACE. In order for features to be adopted however, there must be some level of similarity between the two items. For example, given that Neath (2000) noted that “it seems less plausible that modality-independent features that arise from processing a tone would be adopted into the modality-independent features that arise from processing a speech token,” it seems even more implausible that features representing complex tapping would be adopted into features representing a letter.

Although feature adoption cannot easily explain the finding that complex spatial tapping altered the ACE, the idea that task difficulty affects the ACE through the process of redintegration has been suggested (e.g., see Neale & Tehan, 2007). Indeed, Neale and Tehan proposed that intact memory traces can be retrieved directly without redintegration. As task difficulty increases, memory traces are more degraded, and reliance on redintegration increases. Similarity however, would constrain the set of likely responses (i.e. items that sound alike) and facilitate redintegration. Therefore, dissimilar items, because they do not specify any subset in long term memory, would be more difficult to reconstruct and would suffer more from task difficulty than similar items. According to such a view, complex spatial tapping and syncopated tapping (e.g., see Larsen & Baddeley, 2003) alter the ACE because they increase task difficulty, as evidenced by the poorer level of performance in these conditions. Simple spatial tapping, although it affected performance, had a much lower impact, which may not have been sufficient to produce a reliable effect on the redintegration process. It remains to be determined however, how task difficulty and the use of complex spatial tapping affect the integrity of the memory trace.

The present study does not question the hypothesis according to which the irregular rhythm induced by syncopated tapping interferes with language production. However, we argue that tapping a complex spatial pattern that does not vary according to a temporal dimension is sufficient to interfere with the ACE and that explanations based on the use of modules specific to the processing of verbal information (e.g., Baddeley, 1986), on the similarity between the TBR material and the interfering task (e.g., Nairne, 1990), or on organisational processes (e.g., Jones et al., 2004) are not adequate in their present form to explain the results. Instead, we suggest that complex spatial tapping increased task difficulty and altered the ACE by modulating the efficacy of the redintegration process. More generally, the finding that non-verbal information can interact with a purely verbal phenomena such as the ACE suggests that STM mechanisms may be less specific than has been originally suggested.

Author Notes

Thanks are due to Chris Bishop and Alex Penney for assistance in conducting the experiments. This research was supported by grants from NSERC to IN and to AMS.
Correspondence can be addressed to Katherine Guérard, École de Psychologie, Université Laval, Québec, G1V 0A6, Canada. Email can be sent to katherine.guerard.1@ulaval.ca.

References

Andrade, J., Kemps, E., Werniers, Y., May, J., & Szmalec, A. (2002). Insensitivity of visual short-term memory to irrelevant visual information. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 55A*, 753-774.

Baddeley, A. D. (1966). Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 18A*, 362-365.

Baddeley, A. D. (1986). *Working Memory*. Oxford, UK: Clarendon Press.

Baddeley, A. D. (2000). The phonological loop and irrelevant speech effect: Some comments on Neath (2000). *Psychonomic Bulletin and Review, 7*, 544-549.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829-839.

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (pp. 47-90). New York, NY: Academic Press.

Baddeley, A. D., Lewis, V. J., & Vallar, G. (1984). Exploring the articulatory loop. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 36A*, 233-252.

Colle, H. A., & Welsh, A. (1976). Acoustic masking in primary memory. *Journal of Verbal Learning and Verbal Behavior, 15*, 17-31.

Coltheart, V. (1993). Effect of phonological similarity and concurrent irrelevant articulation on short-term-memory recall of repeated and novel word lists. *Memory & Cognition, 21*, 539-545.

Conrad, R. (1964). Acoustic confusions in immediate memory. *British Journal of Psychology, 55*, 75-84.

Guérard, K., & Tremblay, S. (2008). Revisiting evidence for modularity and functional equivalence across verbal and spatial domains in memory. *Journal of Experimental Psychology: Learning, Memory & Cognition, 34*, 556-569.

Henson, R., Hartley, T., Burgess, N., Hitch, G., & Flude, B. (2003). Selective interference with verbal short-term memory for serial order information: A new paradigm and tests of a timing-signal hypothesis. *The Quarterly Journal of Experimental Psychology, 56A*, 1307-1334.

Jones, D. M. (1993). Objects, streams, and threads of auditory attention. In A. D. Baddeley & L. Weiskrantz (Eds.), *Attention: Selection, awareness, and control: A tribute to Donald Broadbent* (pp. 87–104). Oxford, UK: Clarendon Press.

Jones, D. M., Farrand, P., Stuart, G., & Morris, N. (1995). Functional equivalence of verbal and spatial information in serial short-term memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 1008-1018.

Jones, D. M., Hughes, R., W., & Macken, W. J. (2006). Perceptual organization masquerading as phonological storage: Further support for a perceptual-gestural view of short-term memory. *Journal of Memory and Language, 54*, 265–281.

Jones, D. M., & Macken, W. J. (1993). Irrelevant tones produce an irrelevant speech effect: Implications for phonological coding in working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19*(2), 369-381.

Jones, D. M., Macken, W. J., & Nicholls, A. P. (2004). The phonological store of working memory: Is it phonological and is it a store? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*, 656-674.

Kemps, E. (2001). Complexity effects in visuo-spatial working memory: Implications for the role of long-term memory. *Memory, 9*, 13-27.

Klauer, K. C., & Zhao, Z. (2004). Double dissociations in visual and spatial short-term memory. *Journal of Experimental Psychology: General, 133*, 355-381.

Larsen, J. D., & Baddeley, A. (2003). Disruption of verbal STM by irrelevant speech, articulatory suppression, and manual tapping: Do they have a common source? *The Quarterly Journal of Experimental Psychology, 56A*, 1249-1268.

Larsen, J. D., Baddeley, A., & Andrade, J. (2000). Phonological similarity and the irrelevant speech effect: Implications for models of short-term verbal memory. *Memory, 8*, 145-157.

LeCompte, D. C., Neely, C. B., & Wilson, J. R. (1997). Irrelevant speech and irrelevant tones: The relative importance of speech to the irrelevant speech effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23*, 472-483.

Longoni, A. M., Richardson, J. T. E., & Aiello, A. (1993). Articulatory rehearsal and phonological storage in working memory. *Memory & Cognition, 21*, 11-22.

Meiser, T., & Klauer, K. C. (1999). Working memory and changing-state hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 1272-1299.

Murray, D. J. (1967). The role of speech responses in short-term memory. *Canadian Journal of Psychology, 21*, 263-276.

Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition, 18*, 251-269.

Neale, K., & Thehan, G. (2007). Age and redintegration in immediate memory and their relationship with task difficulty. *Memory & Cognition, 35*, 1940-1953.

Saito, S. (1993). The disappearance of phonological similarity effect by complex rhythmic tapping. *Psychologia, 36*, 27–33.

Saito, S. (1994). What effect can rhythmic finger tapping have on the phonological similarity effect? *Memory & Cognition, 22*, 181-187.

Saito, S. (1997). When articulatory suppression does not suppress the activity of the phonological loop. *British Journal of Psychology, 88*, 565-578.

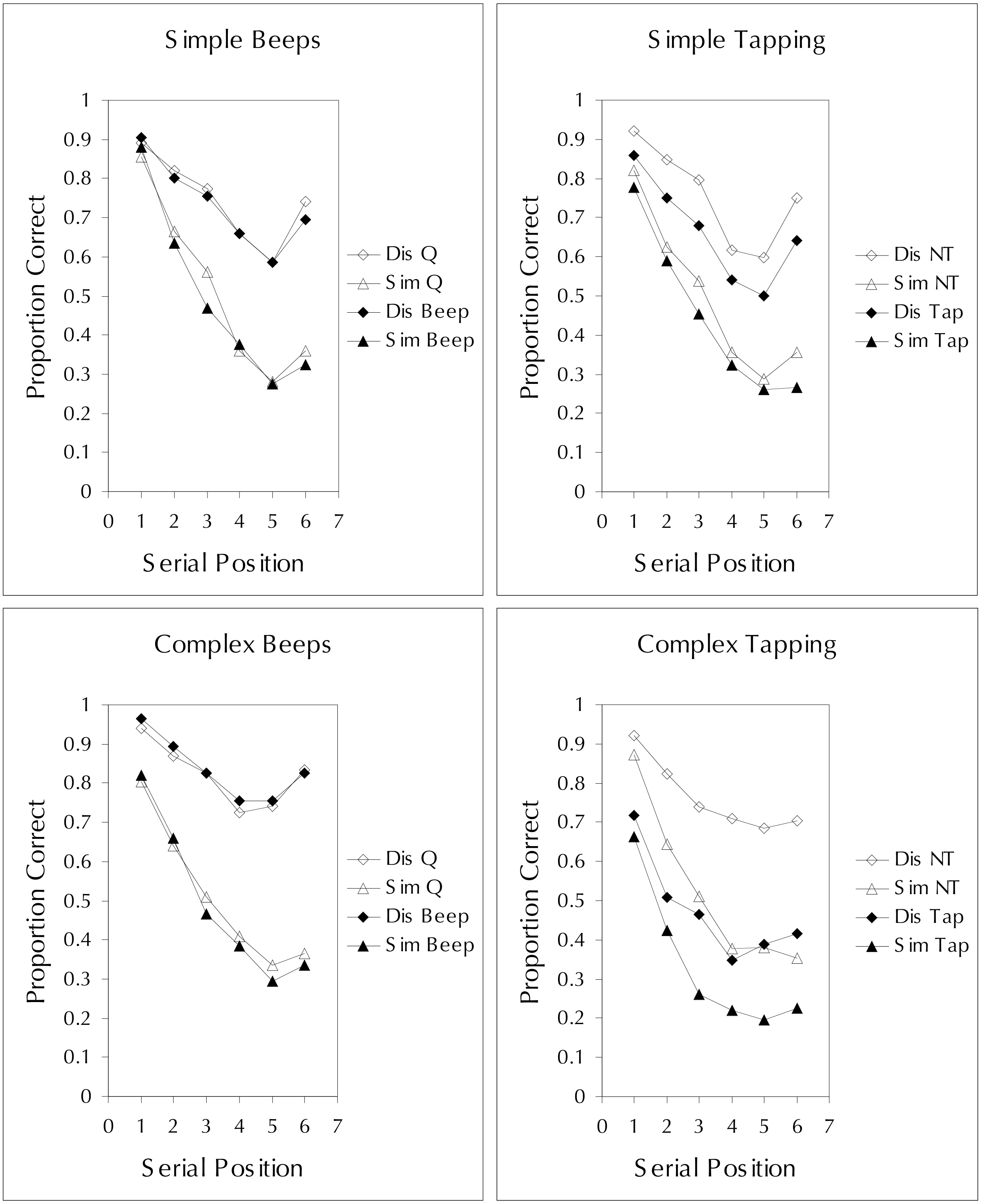
Surprenant, A. M., Neath, I., Bireta, T. J., & Allbritton, D. W. (2008). Directly assessing the relationship between irrelevant speech and irrelevant tapping. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 62,* 141-149.

Zimmer, H. D., Speiser, H. R., & Seidler, B. (2003). Spatio-temporal working-memory and short-term object-location tasks use different memory mechanisms. *Acta Psychologica, 114*, 41–65.

Figure Caption

Figure 1. The proportion of letters correctly recalled in order as a function of acoustic confusability (dissimilar or similar) and the presence (Beep) or absence (Q) of beeps (left column) or the presence (Tap) or absence (NT) of concurrent tapping (right column) in the simple (top) and complex (bottom) conditions.

Figure 1


Simple Beeps
Proportion Correct
Serial Position
Dis Q
Sim Q
Dis Beep
Sim Beep
Simple Tapping
Dis NT
Sim NT
Dis Tap
Sim Tap
Complex Beeps
Complex Tapping