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Inhibitory Control Processes in Free Recall: Benefits and Costs to Performance

John E. Marsh[1,2], Patrik Sörqvist[2,3], Helen M. Hodgetts[4,5], C. Philip Beaman[6], and Dylan M. Jones[7]

[1]School of Psychology, University of Central Lancashire, Preston, Lancashire, UK.

[2]Department of Building, Energy, and Environmental Engineering, University of Gävle, Gävle, Sweden.

[3]Linnaeus Centre HEAD, Swedish Institute for Disability Research, Linköping University, Linköping, Sweden.

[4]École de psychologie, Université Laval, Québec, Québec, Canada.

[5]Department of Applied Psychology, Cardiff Metropolitan University, Cardiff, UK.

[6]School of Psychology & Clinical Language Sciences, University of Reading, Reading, UK.

[7]School of Psychology, Cardiff University, Cardiff, UK.

RUNNING HEAD: Inhibitory Control Processes in Free Recall

Correspondence: John E. Marsh, School of Psychology, University of Central Lancashire, Preston, United Kingdom, PR1 2HE.

Phone: + 44 1772 893754

Fax : +44 1772 892925

E-mail: jemarsh@uclan.ac.uk

Abstract

How is semantic memory influenced by individual differences under conditions of distraction? This question was addressed by observing how visual target words—drawn from a single category—were recalled whilst ignoring spoken distracter words that were either members of the same, or members of a different (single) category. Distracter words were presented either synchronously or asynchronously with target words. Recall performance was correlated with participants' working memory capacity (WMC), which was taken to be an index of the capacity for distracter inhibition. Distraction was greater from semantically similar words and distraction was greater when the words were presented synchronously. WMC was related to disruption only with synchronous, not asynchronous, presentation. Subsequent experiments found more distracter inhibition – as measured by subsequent negative priming of distracters – amongst individuals with higher WMC but this may be dependent on targets and distracters being comparable category exemplars: With less dominant category members as distracters, target recall was impaired – relative to control – only amongst individuals with low WMC. The results demonstrate distracter inhibition occurring only in conditions where target-distracter selection is challenging. Inhibition incurs costs to subsequent performance, but there is an immediate price for not inhibiting.

Keywords: Auditory Distraction; Working Memory Capacity; Source Monitoring; Free Recall, Negative Priming, Inhibition.

To function adaptively in a changing environment, the cognitive system must find a way to attend selectively to information relevant to its present goal while avoiding distraction from irrelevant information. This is a particular problem with irrelevant auditory information. Often, visual distracters can be excluded from the visual field, but this is not generally an option for auditory distracters which are processed obligatorily regardless of where within the environment visual attention is focused. One way to study the cognitive mechanisms of selective attention is by means of a distraction paradigm. A particular problem for the general case of the cognitive system trying to focus on its own goals to the exclusion of task-irrelevant distracters is evident within the cross-modal semantic distraction task. Within this procedure, the participants are visually-presented with target words belonging to the same category (e.g., ‘Fruit’) studied either in silence or against a background of to-be-ignored auditory words (distracters) that either belong to the same category as the target items (other ‘Fruit’) or a different category (e.g., ‘Tools’). In this (free recall) task, correct recall is impaired when target and distracter words are members of the same category (Neely & LeCompte, 1999) particularly if distracters are presented alongside the to-be-remembered list and intrusions of distracters into the recall protocol are also observed (Beaman, 2004; Neely & LeCompte, 1999; Marsh, Hughes, & Jones, 2008, 2009; Sörqvist, Marsh, & Jahncke, 2010; for comparable effects using phonologically defined (e.g., rhyme) categories, see Marsh, Vachon, & Jones, 2008).

The cross-modal semantic distraction paradigm has proved to be a useful tool to explore key phenomena in selection of the correct item from a range which might provide a reasonable semantic “fit” such as source-monitoring (Marsh et al., 2008), and fluency in verbal retrieval (Jones, Marsh, & Hughes, 2012; Marsh & Jones, 2010), and also how hemispheric specializations in different aspects of language processing might underlie semantic and non-semantic selection processes (Beaman, Bridges & Scott, 2007; Marsh, Pilgrim, & Sörqvist, 2013; Sörqvist et al., 2010). Here, we use the paradigm to explore how the cognitive system inhibits auditory distracters to bring about, through selective attention, the successful retrieval of visual target material (Hughes & Jones, 2003; Marsh, Beaman, Hughes, & Jones, 2012). We examine how this inhibitory process (co-) varies with the particular disposition of the individual for attentional control and what consequence, if any, inhibition has for the recall of target information.

Recent evidence from cross-modal semantic distraction suggests that retrieval of target visual material is accompanied by the inhibition of auditory distracters (Marsh et al., 2012). It is perhaps surprising that individual differences in working memory capacity (WMC)—measured with complex span tasks that combine short-term memory processes with concurrent distracter activities—seem unrelated to this particular form of disruption (Beaman, 2004). The puzzle here is that individual differences in WMC are typically found to modulate auditory distraction as studied in other paradigms (e.g., Sörqvist, 2010a, b; but see Sörqvist, Marsh & Nöstl, 2013) and is generally related to performance in situations wherein “task success is aided by inhibiting not only task-specific information but also irrelevant thoughts and distracting events” (Redick, Heitz, & Engle, 2007, pp. 127). For example, Conway, Cowan and Bunting (2001) found that low-WMC participants were more likely to report hearing their own name on a supposedly unattended channel during a dichotic listening task.

Consonant with the idea that individual differences in WMC reflect the ability to control distraction (Engle, 2002), Sörqvist, Stenfelt and Rönnberg (2012) showed that a greater focus on a to-be-attended channel (a visual-verbal source in this case) resulted in greater inhibition of irrelevant auditory processing, especially in high-WMC individuals. This supports the idea that low-WMC individuals have poorer inhibitory capabilities, thus failing to inhibit the auditory material at early perceptual processing stages (Sörqvist, Stenfelt, & Rönnberg, 2012; see also Tsuchida, Katayama, & Murohashi, 2012). Evidence also suggests that high WMC attenuates the disruptive effect a deviating sound (e.g., the sound ‘m’ in the sequence ‘k k k k m k k k’) has on task performance (Hughes, Hurlstone, Marsh, Vachon & Jones, 2013; Sörqvist, 2010a; Sörqvist, Nöstl, & Halin, 2012; Sörqvist et al., 2013). Moreover, although WMC does not appear to modulate the effect of semantic similarity between targets and distracters on correct recall, both WMC and age modulate the false recall of semantically-related distracters, with high-WMC participants (Beaman, 2004) and younger adults (Bell, Buchner, & Mund, 2008) showing fewer intrusions.

Collectively, these studies suggest that the capacity to focus attention on target material and the capacity to inhibit to-be-ignored material are distinguishing features of individuals who vary in WMC. However, if failure to adequately inhibit the processing of to-be-ignored distracters is the distinguishing feature of low-WMC individuals (e.g., Heitz & Engle, 2007; Kane & Engle, 2000), then why does WMC not modulate the damaging impact of related distracters on correct recall in the cross-modal semantic distraction paradigm?

One possibility is that the disruption to correct recall by related distracters is governed by target-distracter selection processes. In the study by Beaman (2004), the distracters were presented in a retention interval between target encoding and recall. In this situation, the targets and distracters are easy to distinguish temporally and contextually, and target encoding does not necessitate concurrent distracter inhibition

(Marsh et al., 2008). A key idea in the present study is that (undesired) sound processing reduces visual target processing (Weisz & Schlittmeier, 2006), when auditory and visual material are presented concurrently, and WMC serves to distinguish relevant from irrelevant material within temporally-bounded windows or search sets (cf. Unsworth & Engle, 2007). This can happen both at retrieval in which case the window is relatively wide (resulting the WMC- and age-related differences in intrusions reported by Beaman (2004) and Bell et al. (2008) during a retention interval) and at encoding, in which case the window is not a search set but rather an attentional focus and is relatively narrow. We presume that if to-be-ignored speech items reach higher activation levels for low-WMC individuals than for high-WMC individuals at encoding due to differences in the capacity for distracter inhibition, then WMC should modulate any distracting impact on the correct recall of targets. Thus, any impact of WMC is most likely to be seen when targets and distracters are presented in phase, that is, synchronously—than if presented asynchronously. This reasoning suggests an effect of synchrony of presentation which has not previously been reported in semantic distraction studies, and has not been found in studies using serial short-term recall (e.g., Salamé & Baddeley, 1982). However, serial memory effects are not mediated by the semantic-relatedness between distracters and targets (Buchner, Irmen, & Erdfelder, 1996) so that any greater control by high-WMC individuals specifically of semantic activation within memory as a result of superior inhibition (Rosen & Engle, 1998) might impact on semantic memory regardless of the effects on serial, episodic and short-term memory.

To preview the present study, we provide the first tests of the hypothesis that the between-sequence semantic similarity effect is modulated by individual differences in the capacity for distracter-inhibition, as measured by WMC. In

Experiment 1 we first seek support for the hypothesis that differences in the susceptibility to the between-sequence semantic similarity effect occur when target and distracter representations are maximally co-active—as with synchronous presentation—such that the system has to select one source of activated representation (that emanating from visual origin) over another (that arising from auditory origin) in the absence of distinctive temporal cues. In Experiments 2-4 we further address the capacity for distracter inhibition using a setting within which the extent of distracter inhibition is gauged by impairment in performance when the distracters later become targets (negative priming (NP); Marsh et al., 2012). Further, we test the hypothesis that differences the capacity for distracter inhibition—as measured by WMC—will be observed when the distracters are strong competitors for recall. This is presumed to be the case when distracters are high in output-dominance (i.e., frequently given as an example of a category in category-norm studies) and hence (according to the strength-dependent competition assumption) potentially more interfering than if distracters are low in output dominance (Anderson, Bjork, & Bjork, 1994). This pattern of results would strongly support the view that WMC reflects the efficiency of cognitive control processes such as distracter-inhibition in modulating specifically semantic distraction.

Experiment 1

Method

Participants

Seventy-six students (40 from Cardiff University and 36 from the University of Central Lancashire) took part in the study. All reported normal or corrected-to-normal vision and normal hearing, and spoke English as their first language. They received course credit or an honorarium for their participation.

Apparatus/Materials

The experiment was run using Superlab Pro (Cedrus Corporation) software. Across two sessions, participants received 36 trials in which they were presented with 15 to-be-remembered words (targets) and 15 to-be-ignored words (distracters). Targets appeared centrally on the computer screen in black 72-point Times font on a white background at a rate of one every 1.5 s (750 ms on, with a 750 ms inter-stimulus interval; ISI). Distracters were presented over stereo headphones at 65 dB(A) and at a rate of one every 1.5 s (750 ms on, 750 ms ISI). Depending on the condition, the distracters were either presented synchronously with the distracters (Synchronous condition) or in the ISI between the targets when a blank (white) screen was presented (sandwiched between targets during study; Asynchronous condition). The distracters were digitally recorded in a male voice at an even-pitch and sampled with a 16-bit resolution at a sampling rate of 44.1 kHz using Sound Forge 5 (Sonic Inc., Madison, WI, 2000).

Thirty words were chosen from each of 36 semantic categories taken from the Van Overschelde, Rawson, and Dunlosky (2004) category norms. Items from odd-ranked positions in the category-norm lists were assigned to the to-be-recalled (TBR) target lists and items from even positions were to-be-ignored (TBI) distracters. The 36 selected categories were first arranged into pairs of unrelated categories (e.g., “Fruit”, “Carpenter’s Tools”).

There were two experimental blocks that were separated by one week. There were 18 trials in both blocks respectively: 9 in which targets and distracters were semantically related and 9 in which they were unrelated. On the related trials, in the first block, the auditory distracters were taken from the same category as the targets, thus only one of the categories in the pair was presented. On unrelated trials, both categories in the pairs were presented. Thus the distracter items were taken from the semantically-unrelated category (e.g., “Fruit”) that was paired with the target category (“Carpenter’s Tools”). For the second block of 18 trials, the related trials incorporated the categories that were not used on the related trials in the first block. For example, if the pair was Fruit and Carpenter’s tools, and Fruit was used as the category in block 1, then Carpenter’s tools was used in block 2. For the unrelated trials in block 2, the same category-pairs were used as in block 1, but the items that acted as targets in block 1 was presented as distracters in block 2 and the items that acted as distracters in block 1 was presented as targets in block 2.

The presentation order of exemplars within each to-be-remembered and to-be-ignored sequence was random but the same for each participant. Half of the participants received a semantically-related trial first, followed by a semantically-unrelated trial (with trials alternating thereafter between related and unrelated even across blocks) whereas this order was reversed for the other half of the participants. Moreover, half of the participants started with the Synchronous block and half started with the Asynchronous block. Categories were assigned such that across participants there was an equal likelihood of each category being an unrelated or related category, presented in the Synchronous or Asynchronous condition, and experienced in block 1 or block 2 of the experiment.

Design

A 2 (Phase of Presentation: synchronous versus asynchronous) × 2 (Target-Distracter Relation: related versus unrelated) within-participants design was used. The dependent variables were (a) the proportion of target words correctly recalled and (b) the number of intrusions, that is words recalled that did not appear as targets on a given list.

Procedure

Participants were first tested for their operation span (OSPAN) using an automated OSPAN program (see Unsworth, Heitz, Schrock, & Engle, 2005). For this task, the participants were visually-presented with lists of mathematical-operation questions (e.g., "Is 7 × 5 + 3 = 38?") and to-be-recalled letters. The participants' task was to respond with a 'yes' or a 'no' to each question and to select the to-be-recalled letters in order of presentation from an array at the end of each list. OSPAN score was used as an indicator of WMC. Participants were then tested individually in soundproof booths and were seated at a distance of approximately 60 cm from a PC monitor. Participants wore headphones throughout the experiment. Participants began by reading standardized instructions and they were told specifically that they should ignore the distracter words and that they would not be asked anything about them during the experiment. They were given response booklets in which to recall the target words (a grid with space for 15 words was provided for each trial).

The target words were presented one at a time on the computer screen and after all 15 targets (and 15 distracters) had been presented, the computer displayed the prompt "recall" on the screen. Participants then had 45 s to write down on the response sheets, in any order, as many of the target items as they could. Through instructions, guessing on the task was explicitly discouraged. After the 45 s recall period, a tone in the headphones signalled the end of the trial. Pressing the space bar initiated presentation of the next list. One practice trial (in quiet) was given at the start of each block after which participants had the opportunity to ask any questions before the main trials began. The first experimental session lasted approximately 50 min and the second took about 30 min.

Results

Absolute OSPAN scores were computed (see Unsworth et al., 2005). When four extreme outliers were removed, the mean OSPAN score was 39.07 (SE = 1.58, range 14-69, N = 72). The skewness was .16 (SE = .28) and the kurtosis was -.51 (SE = .56).

Correct responses

Responses were scored according to a free recall criterion; an item was scored as correct regardless of its position. As can be seen in Figure 1 (Panel A), proportion correct recall was impaired by the presence of to-be-ignored words that belonged to the same category as the to-be-recalled items in comparison with when the to-be-ignored words belonged to a different category, and more so when presentation of the target and non-target items were synchronous. Skewness and kurtosis for the four experimental conditions were fairly normal (synchronous related = 0.32 and 0.31; synchronous unrelated = -0.003 and -0.09; asynchronous related = -0.21 and -0.31; asynchronous unrelated = -0.17 and -0.35, respectively). In the following analysis we use a covariate as a straightforward way of combining a continuous variable (the OSPAN scores) with the factorial analysis (i.e., addressing the potential interaction between target-distracter similarity and synchronicity). This analysis makes it possible to test if an interaction is present when we statistically control for WMC. If the interaction is present then this means that the interaction is also present under the assumption that all participants have the same WMC. Moreover, at the same time we can also test if factors interact with WMC. If there is indeed an interaction, this means that the magnitude of the effect of the factors depends on individual differences in WMC. The analysis with the covariate is then followed up so that any interactions with OSPAN can then be understood.

A 2 (Phase of Presentation: synchronous versus asynchronous) × 2 (Target-Distracter Relation: related versus unrelated) analysis of co-variance (ANCOVA) with OSPAN as a covariate variable revealed a main effect of Phase of Presentation, $F(1, 70) = 7.08$, $MSE = 0.003$, $p < .0097$, $\eta_p^2 = .09$, a main effect of Target-Distracter Relation, $F(1, 70) = 33.96$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .33$, and a significant interaction between these two factors, $F(1, 70) = 20.20$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .22$. OSPAN interacted significantly with Target-Distracter Relation, $F(1, 70) = 4.58$, $MSE = 0.001$, $p = .036$, $\eta_p^2 = .06$, with Phase of Presentation, $F(1, 70) = 5.59$, $MSE = 0.003$, $p = .021$, $\eta_p^2 = .07$, and the three-way interaction was significant, $F(1, 70) = 14.13$, $MSE = 0.001$, $p < .001$, $\eta_p^2 = .17$. Control analyses with Block Order (synchronous versus asynchronous first) as an additional factor revealed no main effect of Block Order and none of its interactions with Phase of presentation and/or Target-Distracter Relation was statistically significant.

To tease apart the three-way interaction, we obtained a person-specific measure of susceptibility to semantic auditory distraction (the "between-sequence semantic similarity effect") by subtracting the total number of correct recalls in the related speech condition from correct recalls in the unrelated speech condition (i.e., a larger value represents a larger effect), in the synchronous ($M = 0.064$, $SD = 0.062$; skewness = -0.36; kurtosis = -0.03) and asynchronous ($M = 0.039$, $SD = 0.046$; skewness = -0.11; kurtosis = 0.37) conditions. These difference scores were correlated with OSPAN. As can be seen in Figure 2 (panel A), higher OSPAN scores were associated with a lower magnitude of the between-sequence semantic similarity effect with synchronous presentation, $r(70) = -.41$, $p < .001$, 95 % CI [-.63, -.19], but no relationship was found with asynchronous presentation (panel B), $r(70) = .14$, $p = .24$, 95 % CI [-.09, .38]. Notably, these two correlation estimates are significantly different

(Meng, Rosenthal, & Rubin, 1992)[1], $z(70) = 3.28$, $p < .001$, 95 % CI [.23, .73]. Hence, WMC modulates the between-sequence semantic similarity effect with synchronous presentation but not with asynchronous presentation.

Intrusions

We also analysed false recalls of spoken distracter words that appeared in the recall protocols. The frequency of these intrusion errors are related to WMC (Beaman, 2004) and may thus further elucidate the role of distracter inhibition in short-term memory. A response that matched one of the fifteen items from the even positions in the Van Overschelde et al. (2004) norms (that were presented as distracters on related trials) was scored as an intrusion, even for the unrelated condition in which those items had not been presented, which provides an estimate of false recall probability (see Beaman, 2004; Marsh et al., 2008). Figure 1 (panel B) shows the mean number of related-item intrusions for each condition. Skewness and kurtosis for the four experimental conditions were relatively high, as is typical with these dependent variables (synchronous related = 1.43 and 2.57; synchronous unrelated = 1.60 and 4.41; asynchronous related = 1.24 and 1.99; asynchronous unrelated = 2.00 and7.31, respectively).

A 2 (Phase of presentation: synchronous versus asynchronous) × 2 (Target-Distracter Relation: related versus unrelated) ANCOVA with OSPAN as a covariate revealed a main effect of Phase of Presentation, $F(1, 70) = 57.30$, $MSE = 8.11$, $p < .001$, $\eta_p^2 = .45$, a main effect of Target-Distracter Relation, $F(1, 70) = 84.60$, $MSE = 2.77$, $p < .001$, $\eta_p^2 = .55$, and a significant interaction between these two factors, $F(1, 70) = 85.76$, $MSE = 2.75$, $p < .001$, $\eta_p^2 = .55$. Again, OSPAN interacted significantly with Target-Distracter Relation, $F(1, 70) = 37.64$, $MSE = 2.77$, $p < .001$, $\eta_p^2 = .35$, with Phase of Presentation, $F(1, 70) = 16.26$, $MSE = 8.11$, $p < .001$, $\eta_p^2 = .19$, and the three-way interaction was significant, $F(1, 70) = 37.47$, $MSE = 2.75$, $p < .001$, $\eta_p^2 = .35$. Again, control analyses with Block Order revealed no main effect or interactions with this factor.

To obtain a person-specific measure of susceptibility to intrusions from speech, the total number of intrusions (false recalls) in the unrelated speech condition was subtracted from intrusions in the related speech condition (i.e., larger values represent greater susceptibility), in the synchronous (M = 4.17, SD = 4.09; skewness = 1.25; kurtosis = 1.97) and asynchronous (M = 2.99, SD = 3.00; skewness = 0.09; kurtosis = 0.26) conditions separately. As can be seen in Figure 3, higher OSPAN scores were associated with a lower susceptibility to intrusions from speech both with synchronous presentation (panel A), $r(70) = -.59$, $p < .001$, 95 % CI [-.78, -.40], and with asynchronous presentation (panel B), $r(70) = -.33$, $p = .005$, 95 % CI [-.56, -.11]. This replicates previous findings of a relationship between WMC and semantically-related intrusions regardless of synchrony of targets and distracters (Beaman, 2004). However, these two correlation estimates are significantly different in magnitude (Meng et al., 1992), $z(70) = 2.46$, $p = .014$, 95 % CI [.07, .54]. It should be noted, though, that the high skewness values of the difference scores in the synchronous condition could have distorted this comparison. In all, WMC constrains susceptibility to intrusions from speech, both with synchronous and asynchronous presentation, and there is indication that WMC does so to a greater extent with synchronous presentation.

To further elucidate how WMC constrains the window of attentional focus and processing at encoding, a dominance analysis was performed whereby each intrusion was assigned a dominance value based upon frequency of production within category norms (Van Overschelde et al., 2004). Where participants made no intrusions this was treated as missing data. The mean dominance of intruding exemplars was 0.32 (SD = 0.20; N = 70) in the related target-distracter relation condition, 0.37 (SD = 0.22; N = 61) in the unrelated synchronous condition, 0.32 (SD = 0.19; N = 71) in the related asynchronous condition, and 0.43 (SD = 0.20; N = 62) in the unrelated asynchronous condition. OSPAN was positively correlated to the dominance of intruding exemplars in the related target-distracter relation condition with synchronous presentation, $r(68) = .33$, $p = .006$. Corresponding correlations in the other conditions were very weak (unrelated synchronous, $r = -.07$, related asynchronous, $r = .02$, unrelated asynchronous, $r = .04$). Hence, lower WMC was associated with a greater tendency to falsely recall low-dominant exemplars, but only under conditions of synchronous presentation of targets and distracters. The relationship between WMC and false recall cannot therefore be dismissed as a by-product of enhanced (but inaccurate) guessing associated with poorer overall recall by low WMC individuals. Moreover, the finding that lower WMC was associated with a greater tendency to recall low-dominant exemplars is consistent with the notion that for lower WMC individuals, those low-dominant distracters reach higher activation thresholds.

Discussion

Experiment 1 demonstrated that the between-sequence semantic similarity effect is greater when the targets and distracters are synchronously presented, and that this relationship is moderated by WMC. This was reflected in a greater rate of intrusion of related distracters and, strikingly, diminished correct recall with synchronous relative to asynchronous presentation for low-WMC individuals. Overall, the pattern of data is consistent with the notion that participants with lower inhibitory capabilities correctly recall fewer target items, but only when the target-selection processes is challenged by the simultaneous presence of distracters. In

Experiment 2, we sought further, and this time more direct, evidence for the assumption that the distracters are indeed inhibited to a greater degree by high-WMC individuals. Moreover, we addressed a theoretically important claim previously lacking empirical evidence: that the between-sequence semantic similarity effect is a consequence of distracter inhibition, inhibitory activity spreading from to-be-ignored to semantically-related to-be-recalled items (Marsh et al., 2008; Marsh et al., 2012; see also Marsh, Sörqvist, Beaman, & Jones, 2013, for a related idea within a separate domain).

Experiment 2

In a recent set of experiments, Marsh et al. (2012) used a NP paradigm (Figure 4) to elucidate the role of inhibition in semantic auditory distraction. In this study, free recall was impaired for target items in trial n+1 (the probe trial) if they had served as distracters on trial n (the prime trial). However, this NP effect only occurred if the targets at probe were high output-dominant members of the same category as the to-be-recalled items when presented as distracters at prime (Marsh et al., 2012, Experiment 2). For prime trials in which distracters were low output-dominant members of the to-be-remembered category or were unrelated to that category, recall was enhanced rather than impaired when those same distracters were presented as to-be-recalled items on the probe trial (positive priming; PP). In other words, distracters were inhibited when, at prime, they were strong competitors for retrieval—such as when they represented high-dominant category members—but not when they were weak competitors, such as when they represented low-dominant category members.

It has been argued that the between-sequence semantic similarity effect is a result of inhibition of distracter items, possibly through inhibition spreading to target items (Marsh et al., 2008, 2009, 2012; Sörqvist et al., 2010). If this is the case, there should be a positive relationship between the NP effect and the between-sequence semantic similarity effect. However, this was not observed in the study by Marsh et al. (2012). There are several possible reasons for this inconsistency. One possibility is that the relationship between the between-sequence semantic similarity effect and NP holds only when the targets and distracters at study are comparable in terms of their output-dominance (item-strength), precluding the use of retrieval heuristics based upon item availability. For example, in the case whereby distracters are high in output-dominance, and targets are low in output-dominance, the strength of the relationship between targets and the category-representation can be used to exclude distracters at prime (identified by their strong category membership), therefore little inhibition may be required and therefore no impact (NP) is seen on the ignored repetition trial. Thus inhibition of distracters may not be essential for successful recall of targets since retrieval can operate through discrimination-based monitoring processes (cf. Schacter, Israel, & Racine, 1999). Another possibility is that the relationship between the between-sequence semantic similarity effect and NP depends on individual differences in the capability of distracter inhibition as measured by WMC.

Evidence that distracter inhibition is resource-dependent has been found in the context of perceptually-based NP. For example, de Fockert, Mizon and D'Ubaldo (2010) report that the availability of cognitive control resources appears to be a prerequisite for NP. Moreover, NP has been shown to be stronger in high-WMC individuals (Conway, Tuholski, Shisler, & Engle, 1999), suggesting that individuals with superior cognitive control capabilities (high-WMC individuals) inhibit distracters at prime to a greater degree than their low-WMC counterparts. Using this evidence as the basis for hypothesizing, the magnitude of NP produced by semantic auditory distracters should increase as a function of individual differences in WMC. High-WMC individuals should more effectively inhibit the semantic distracters and subsequently show stronger NP, but only when the distracters are strong competitors for recall (namely, high output-dominant exemplars) or are matched in output-dominance with the targets such that retrieval heuristics are difficult to deploy (as in Experiment 1). In Experiment 2 we adopt a very similar design to the synchronous condition within Experiment 1 with the exception that in the critical, ignored repetition probe trials, the related speech distracters were re-presented as to-be-remembered targets on the very next trial (cf. Marsh et al., 2012). Therefore, as in Experiment 1, the targets and distracters were comparable in terms of output-dominance.

Method

Participants

Seventy-two students at the University of Central Lancashire took part in the study. All reported normal or corrected-to-normal vision and normal hearing, and spoke English as their first language. They received a small honorarium for their participation.

Materials & Design

Within the block of 36 trials used in the current experiment, 50% of the trials comprised "prime" trials and 50% were "probe" trials. Prime trials were accompanied by distracters whereas no distracters were presented for probe trials.

Thirty words, taken from rank positions 1 to 30, were chosen from each of 36 semantic categories in the Van Overschelde et al. (2004) category norm lists. Each participant received 36 trials comprising one list of 15 visually to-be-remembered words per trial. Half of these were designated as prime trials, and half as probe trials. The experiment was run using E-Prime 2 (Psychology Software Tools Inc.) software. As in Experiment 1, participants were first tested for their operation span (OSPAN) using an automated OSPAN program (see Unsworth et al., 2005). The task was scored using a strict serial recall criterion by assigning one point to each item recalled in the correct serial position.

Prime trials. On prime trials, 15 auditorily-presented to-be-ignored (TBI) words (distracters) were presented alongside the to-be-remembered (TBR) items. TBR items were presented, one item at a time, on the computer screen in lower-case 72-point Times font on a white background at a rate of one every 1.5 s (750 ms on, with a 750 ms inter-stimulus interval; ISI). TBI auditory distracters were presented synchronously with visual to-be-remembered items. In 9 of these trials, the distracter lists were semantically-related to the to-be-remembered lists. To achieve this, 15 items from odd-ranked positions (1, 3, 5...) from the Van Overschelde et al. (2004) category norm lists were assigned to the distracter lists and items from the even positions (2, 4, 6...) were assigned to the TBR lists (e.g., for the category "fruit", the TBI lists would be {apple [1], banana [3], banana [5] etc and the TBR lists would be {orange [2], grape [4], peach [6] etc}). On the remaining nine trials, the auditory distracter items were drawn from categories other than those from which the TBR items were drawn (e.g., if the TBR list was from the category "fruit", as above, the distracter list might be from the category "tools", giving the items {hammer [1], saw [2], drill [3] etc}). Within lists, all items were randomized with respect to their original ranked positions in the Van Overschelde et al. (2004) norms. This random order was the same for all participants.

TBR category lists were also presented to participants in one of two orders (e.g., half the participants might have the category “fruit” as the basis for the TBR items on trial 1, and half might have the category “tools”). The presentation of distracters that were related or unrelated to these lists was counterbalanced across participants such that any given category was presented equally often in the presence of related distracters and unrelated distracters (resulting in four possible combinations across participants for trial 1: fruit (TBR)-fruit (TBI); fruit (TBR)-tools (TBI); tools (TBR)-tools (TBI); tools (TBR)-fruit (TBI)).

Probe trials. A prime trial with auditory distracters accompanying the visual TBR list (18 of the 36 trials) was always immediately followed by a probe trial with no accompanying auditory distracters (the remaining 18 trials). The visually-presented list of TBR items on 9 of these probe trials exactly replicated the auditorily-presented list of distracter items from the preceding prime trial (ignored repetition trials), albeit these items were now presented in a different order. These ignored repetition probe trials always followed prime trials in which the auditory distracters and to-be-remembered lists were semantically-related.

On 9 probe trials that acted as a control condition, the TBR list comprised items were taken from the same semantic category as the TBR list on the previous trial, and therefore categorically-unrelated to the auditory distracters heard previously (see Figure 4). For these trials, the TBR items were drawn from the odd positions (up to position 29) of the semantic category seen previously as TBR material. For example, if the TBR items at prime came from the even positions (up to position 30) of the category “animals” within the Van Overschelde et al. (2004) norms (cat[2], lion [4]…) then the TBR items on a control “probe” trial would be dog[1], horse[3] and so on. Thus, to control for proactive interference, the semantic categories—but not particular items—were repeated across prime and probe lists in all conditions. Pairs of trials were alternated between those that incorporated prime trials followed by ignored repetition trials, and those that incorporated prime trials followed by no-repetition (of distracters). The experimental session took approximately 50 min.

Results

The mean OSPAN score was 40.50 (SE = 1.87, range 6-75, N = 72). The skewness was .07 (SE = .28) and the kurtosis was -.57 (SE = .56).

Correct responses

Correct responses were scored the same way as in Experiment 1. As shown in Table 1, a between-sequence semantic similarity effect (poorer recall in the related vs. unrelated speech condition in the prime trials), and a NP effect, were found. There was poorer recall in the ignored repetition probe condition (wherein the distracter items on the previous trial were repeated as targets) vs. the control condition (wherein the target items were taken from the same semantic category as the target items on the previous trial but were not presented as distracters on that previous trial).

To test whether the magnitude of NP and the between-sequence semantic similarity effects were correlated, and whether individual differences in WMC modulate individual differences in the magnitude of these effects, difference scores were calculated to obtain person-specific measures of the magnitude of NP and the between-sequence semantic similarity effect (Table 1). Distracter inhibition appears to protect correct recall against disruption (Figure 5), as a smaller between-sequence semantic similarity effect (i.e., less disruption of short-term recall), $r(70) = -.40$, $p < .001$ was associated with a greater NP effect (i.e., greater distracter inhibition) . Moreover, WMC was positively correlated with the NP effect, $r(70) = .65$, $p < .001$

(Figure 6) , and negatively correlated with the between-sequence semantic similarity effect, $r(70) = -.35$, $p = .002$ (Figure 7).

Intrusions

To further strengthen the case that the distracters are indeed inhibited, we also analysed the relation between WMC and the tendency to falsely report the distracters at recall as if they were targets. The mean number of intrusions from the speech (related-item intrusions, or "distracter intrusions") on the prime trials can be seen in Table 2. As in Experiment 1, intrusions were more common in the related speech condition than in the unrelated speech condition, and OSPAN was negatively correlated with the person-specific score for susceptibility to intrusions, $r(70) = -.39$, $p < .001$, consistent with Experiment 1 and with Beaman (2004).

As a further measure of distracter inhibition across trials, we also computed the number of prior-list intrusions: That is, responses from the prime target list given amongst responses when tested on the probe target list (see Table 2). These were few in number but slightly more common for control probe trials than for ignored repetition probe trials. OSPAN was negatively correlated with the number of intrusions in the ignored repetition condition, $r(70) = -.39$, $p = .001$ (but positively related to them in the control condition, $r(70) = .24$, $p = .046$), thereby indicating that low-WMC participants were more prone to proactive interference across trials (see also Kane & Engle, 2000; Rosen & Engle, 1998).

Discussion

The results of Experiment 2 seem altogether consistent with the notion that distracters undergo inhibition, and individuals with higher WMC are able to inhibit them to a greater extent than individuals with low WMC, wherein correct recall is more protected in high-WMC individuals and false recall is reduced. A close inspection of Figures 5-7 suggests that the strong relationship between NP and WMC could have emerged because individuals with lower WMC show PP whereas individuals with high WMC demonstrate NP. Subsequent PP is associated with a large between-sequence semantic similarity effect on the previous trial and subsequent NP is associated with a smaller previous between-sequence semantic similarity effect.

At first glance, these results appear inconsistent with those of Marsh et al. (2012) wherein a correlation between NP and the between-sequence semantic similarity effect was not apparent, whereas a negative correlation was found in Experiment 2. One possible reason for the inconsistency is the larger sample size—and concomitant increased statistical power—adopted for the current experiment. Another way in which the findings can be reconciled with the earlier findings of Marsh et al. (2012) is that the relationship between NP and the between-sequence semantic similarity effect holds primarily when retrieval heuristics based on output-dominance are prevented: that is, when the targets and distracters are equated in terms of output-dominance, there is no easy cue—based on item-strength—to identify the targets from amongst the distracters at recall so distracters are instead inhibited at encoding to minimize later confusion. A third possibility is that the relationship between the NP and the between-sequence semantic similarity effect co-varies with individual differences in inhibitory ability as indexed by WMC. That is, because distracter inhibition varies with WMC, any relationship between NP and the between-sequence semantic similarity effect may only become evident when individual differences in inhibitory capability are taken into consideration. These possibilities are explored in Experiment 3 wherein the targets and distracters from Experiment 2 were rearranged such that the targets at prime were low output-dominant (goat[16], zebra[17]…) and the distracters were high output-dominant (dog[1], cat[2]…).

Experiment 3

Method

This was the same as Experiment 2, with the exceptions noted. Forty students at Cardiff University, and thirty-two at the University of Central Lancashire, took part in the study. All reported normal or corrected-to-normal vision and normal hearing, and spoke English as their first language. They received course credit for their participation. None had participated in Experiments 1 and 2.

Complex-span tasks. Two complex-span tasks were used to assess working memory capacity: operation span (OSPAN; Turner & Engle, 1989) and size-comparison span (SICSPAN; Sörqvist et al., 2010). In OSPAN task used here, the participants were visually-presented with lists of mathematical-operation questions (e.g., “Is 7 × 5 + 3 = 38?”) and to-be-recalled words (e.g., DOG). The participants’ task was to respond with a ‘yes’ or a ’no’ to each question and to recall the to-be-recalled words in order of presentation at the end of each list. In SICSPAN, the participants were presented with lists of comparison questions (e.g., “Is LION larger than CAT?”) and to-be-recalled words (e.g., MOUSE). The participants’ task was the same as for the OSPAN task. In both tasks, the total number of to-be-recalled words for each list varied between 2 and 6. There were 3 lists of each length in both tasks (see Sörqvist et al., 2010, for full task details). The two span tasks were conducted in counterbalanced order across participants. Participants undertook the NP task first and came back the next day to complete the two complex-span tasks.

Procedure

The Procedure was the same as in Experiment 2.

Results

The complex-span tasks were scored by assigning one point to each item recall in the accurate list position (as in Experiments 1 and 2). To increase construct validity, we obtained two separate measures of WMC in Experiment 3 (OSPAN and SICSPAN) and calculated a composite score to be used in the analyses. These two tasks are typically highly and positively correlated (e.g., Sörqvist et al., 2010). This was also the case in Experiment 3, $r(70) = .74$, $p < .001$. Therefore, for each participant, a mean task score across the two complex-span tasks was calculated to create a WMC index. The resulting index was used in the statistical analyses. When one extreme outlier, substantially lower than the sample mean (i.e., WMC z-score = -2.96), was removed, the mean WMC composite score (divided by number of trials) was .73 (SE = .02, range .41-.99).

Correct responses

Correct responses were scored the same way as in Experiments 1 and 2. As shown in Table 1, the between-sequence semantic similarity effect (poorer recall in the related vs. unrelated speech condition in the prime trials) and the NP effect were again replicated, as indexed by poorer recall in the distracter-repetition probe condition (wherein the distracter items on the previous trial were repeated as targets) vs. the control condition (wherein the target items were taken from the same semantic category as the target items on the previous trial but were not presented as distracters on that previous trial).

As in Experiment 2, we calculated difference scores to obtain measures of the magnitude of the between-sequence semantic similarity effect and the NP effect (Table 1). Higher WMC was again associated with greater distracter inhibition, as a positive correlation was revealed between WMC composite scores and the NP effect magnitude, $r(69) = .43$, $p < .001$. Also, higher WMC was again associated with a smaller between-sequence semantic similarity effect, $r(69) = -.30$, $p = .011$. However, there was no significant relationship between the magnitudes of the two effects, $r(69) = .15$, $p = .216$. If anything, there was a tendency for a positive correlation (i.e., greater distracter inhibition is associated with greater disruption to correct recall).

These findings raise the question of whether there is a relationship between NP and the between-sequence semantic similarity effect when individual differences in distracter inhibition capacity are statistically controlled. The two effects should be positively related, if the between-sequence semantic similarity effect is (at least in part) a cost experienced as a result of distracter inhibition. To test this hypothesis, a multiple regression analysis was conducted wherein scores for the between-sequence semantic similarity effect were selected as the dependent variable, and the WMC composite score and the NP effect scores were selected as two independent variables. In this model, greater NP was indeed strongly associated with a greater between-sequence semantic similarity effect, as it accounted significantly for a unique set of variance, $\beta = .38$, $t = 3.08$, $p = .003$. However, higher WMC was also associated with a smaller between-sequence semantic similarity effect, $\beta = -.48$, $t = -3.92$, $p < .001$. This somewhat complex pattern can be interpreted as showing that, although greater distracter suppression results in a greater between-sequence semantic similarity effect (Figure 8), and high-WMC individuals inhibit distracters to a greater degree than low-WMC individuals, high-WMC individuals are still less susceptible than low-WMC individuals to the effects of the distracter to correct recall. This would occur if low-WMC individuals fail to suppress the distracters altogether, resulting in a more catastrophic recall disruption (n prime trials) than that resulting from the high-WMC individuals' more successful distracter inhibition.

In sum, the low-WMC individuals show substantial semantic auditory distraction, and little NP, whereas the high-WMC individuals show less semantic auditory distraction, and substantial NP. For this former group, the distraction effect is presumably a consequence of failure to inhibit, for the latter group, the distraction effect is (at least partly) a cost arising from the cognitive overheads of successful distracter-inhibition.

Intrusions

The mean number of intrusions from the speech (related-item intrusions, or "distracter intrusions") on the prime trials can be seen in Table 2. As in Experiments 1 and 2, intrusions were more common in the related speech condition than in the unrelated speech condition. WMC was negatively, but weakly, correlated with the person-specific score for susceptibility to intrusions, $r(70) = -.19$, $p = .05$ (one-tailed). As a measure of proactive interference across trials, we again computed the number of prior-list intrusions (see Table 2). As in Experiment 2, these were few in number but were again slightly more common for control probe trials than for ignored repetition probe trials. OSPAN was not correlated with the number of intrusions in the ignored repetition condition, $r(70) = -.02$, $p = .85$, and only weakly related to intrusions in the control condition, $r(70) = -.19$, $p = .05$ (one-tailed), perhaps indicating that the difference in item-strength between targets and distracters acted as a good distinctiveness cue for both low and high WMC individuals.

Discussion

Experiment 3 provided support for the assumption that the disruption of correct recall by distracter speech is, in part, a residual cost of distracter inhibition (Marsh et al., 2008). The magnitude of free recall disruption inflicted by the distracters (i.e., the between-sequence semantic similarity effect) was related to the extent to which the distracters were inhibited (as measured by the NP effect), but, as Experiment 3 demonstrated, only when a person-specific inhibitory capability (i.e., WMC) was accounted for statistically. In short, inhibition spreads from distracters to category members that are targets for recall and, consequently, recall is impaired. However, without distracter inhibition (or with too little distracter inhibition), as is the case with low-WMC individuals, the distraction effect is even greater. This general conclusion is reinforced by the observation that higher WMC was associated with a smaller between-sequence semantic similarity effect (even though it is, at the same time, associated with a greater NP effect).

Experiment 4

The NP effect reflects the fact that TBR lists, comprising items that had been competitors for retrieval during the previous (prime) trial, were more poorly recalled at the probe trial than non-repeated lists at the probe trial. We assume, therefore, that the occurrence of NP reflects a legacy of an inhibitory process that acts to reduce competition between targets and distracters at prime. Since the strength of the relationship between targets (and distracters) and the parent category from which they are drawn determines the degree of competition (cf. Anderson et al., 1994; Marsh et al., 2008) we would expect the relationship between the between-sequence semantic similarity effect, NP and its moderation by WMC to be influenced by reducing the output dominance of the auditory distracters. Therefore, we investigate a scenario in which targets and competitors at prime are semantically-related but not (strong) competitors. In Experiment 4, the targets and distracters from Experiment 3 were rearranged such that the targets at prime were high-dominant (dog[1], cat[2]…) and the distracters were low-dominant (goat[16], zebra[17]…). The magnitude of the between-sequence semantic similarity effect is a function of distracter dominance, and the effect is typically not manifest with low output-dominant distracters (Marsh et al., 2008, Experiment 4; Marsh et al., 2012). If we suppose that low-WMC individuals do not control the spread of activation from targets during study, low-dominant distracters may receive activation by virtue of their semantic relationship with the target (Kiang & Kutas, 2006; Rosen & Engle, 1997), producing a blocking effect (Kimball & Bjork, 2002; Raaijmakers & Jakab, 2012; Rundus, 1973), rather than a direct inhibition effect, whereby correct recall is reduced. Blocking effects occur when the action of a competing response (in this case recall of the TBR item) is prevented by means other than reducing the activation level of that competing response. That is, when remaining above some conscious threshold, a highly activated response prevents retrieval of competing responses. Blocking is typically described as an occlusion mechanism. Here, retrieval of a related distracter should strengthen the associative link between the (distracter) item and its retrieval cue (in this case the cue is the parent-category) which is also shared with the targets. Distracter retrieval thereby has the effect of decreasing the relative strength of association of list-exemplars with the retrieval cue making them difficult to retrieve. Furthermore, this alteration of link strength through distracter retrieval should increase the tendency for distracters to be persistently retrieved again, thwarting attempts to retrieve targets and eventually leading to a termination in the search process (e.g., Rundus, 1973). Since low-WMC individuals fail to successfully inhibit semantically-related distracters

(Experiments 2 and 3), the action of low-dominant distracters may block target retrieval for these individuals. Hence, a between-sequence semantic similarity effect may emerge for low- (but not for high-) WMC individuals even when the distracters are low-output dominant. If so, there should be a negative relationship between WMC and the between-sequence semantic similarity effect, even in the absence of NP (Marsh et al., 2012).

Method

This was the same as Experiments 2 and 3, with the exception that the distracters at prime were now low-dominant and the targets high-dominant. Thirty-six students at Cardiff University and thirty-six students at the University of Central Lancashire, fulfilling the same criteria as used in Experiments 1, 2, and 3, took part in the study. None had taken part in Experiments 1, 2, or 3.

Results and Discussion

The complex-span tasks were scored the same way as in Experiment 3. Again, the OSPAN and SICSPAN scores were highly correlated, $r(70) = .81$, $p < .001$, and therefore a composite score was produced. The resulting mean WMC score (averaged across trials) was .74 ($SE = .02$, range .33-.99). A small between-sequence semantic similarity effect was found when considering the prime trials within Experiment 4 (see Table 1). Moreover, there was a small positive—not negative—priming effect of having the low-dominant distracter items at prime trials re-presented as targets for recall on the ignored repetition probe trials (see Table 1). Note that overall performance was better for high-dominant targets than low-dominant targets. This reflects the usual tendency for recall to be better for high-dominant than low-dominant targets (Marsh et al., 2012).

Magnitude scores for the NP effect and the between-sequence semantic similarity effect were calculated as in Experiments 2 and 3 (Table 1). In Experiment 4, there was no correlation between WMC and the (positive) priming effect magnitude, $r(70) = -.04$, $p = .751$, and no correlation between the between-sequence semantic similarity effect and the NP effect , $r(70) = .05$, $p = .698$. Higher WMC individuals were, however, less susceptible to the between-sequence semantic similarity effect (Figure 9), $r(70) = -.55$, $p < .001$. A regression analysis with the between-sequence semantic similarity effect as dependent variable, and WMC scores and the priming effect as independent variable, confirmed that WMC explained a significant portion of the variance, $\beta = -.55$, $t = -5.48$, $p < .001$, and the priming effect did not, $\beta = .03$, $t = 0.26$, $p = .80$. Hence, even though the low-dominant distracters of Experiment 4 produced a small between-sequence semantic similarity effect overall, they only disrupted recall amongst individuals in the low WMC range as hypothesized from the blocking view. Taken together, the results of Experiment 4 suggest that low-dominant distracters are not actively inhibited by high-WMC individuals (or indeed by low-WMC individuals). Such related distracters do still disrupt recall, but a marked disruption is only found in individuals with low WMC.

Intrusions

False recalls were relatively few in number, but they were significantly more common for the related speech condition than the unrelated speech condition (see Table 2). Using a person-specific measure of susceptibility to intrusions from speech, higher WMC scores were associated with a lower susceptibility to intrusions, $r(70) = -.24$, $p = .042$, further reinforcing the findings from Experiments 1-3, and extending to include also the situation wherein distracters are low output-dominant category exemplars. Prior-list intrusions (see Table 2) were overall more common in the control probe as compared with the ignored repetition trials due to the intrusiveness of the high output-dominant prime responses during probe. In this case, with low-output dominant distracters, WMC was highly correlated with the number of intrusions in the control condition, $r(70) = -.37$, $p < .001$, but unrelated to intrusions in the ignored repetition condition, $r(70) = -.08$, $p = .524$. Prior-list intrusions were more numerous here than in Experiment 3, presumably because they were higher in item-strength (output-dominance).

General Discussion

The series reported here shows that target-distracter competition at target encoding, manipulated by having the distracters presented synchronously or asynchronously with the targets, modulates the disruption of free recall, with synchronous presentation being more disruptive. Individual variation in WMC qualifies this synchronicity effect, with higher WMC being associated with a lower disruption to correct free recall than low WMC with synchronous, but not asynchronous, presentation (Experiment 1). The competition at target encoding—most pressing with synchronous presentation—is resolved by distracter inhibition, as manifested in impaired recall when previous distracters are subsequently presented as to-be-recalled items (Experiments 2 and 3). This inhibition process protects recall, but comes with a small overhead, as it also impairs target recall (Experiment 3). When the need for distracter inhibition is limited, such as when the distracters are weak competitors, the distracters may still impair target recall, at least for individuals with poor WMC (Experiment 4).

Notably, no relationship between WMC and distraction of correct recall was found in the study by Beaman (2004) in which distracters were presented during a retention interval. It appears, therefore, that the effect of semantic distraction on correct recall is only modulated by WMC when there is a substantial temporal overlap between the presentation of targets and distracters (Experiment 1).

We assume that the driving mechanism behind this finding is that the selection of targets—and the active deletion of distracters—from the to-be-recalled set is most taxing (i.e., requires a high degree of cognitive control capabilities such as effective distracter inhibition) with synchronous presentation. As high-WMC individuals are more capable of inhibiting or suppressing processing when the task is cognitively taxing (Sörqvist, Stenfelt, et al., 2012), the relationship between WMC and the between-sequence semantic similarity effect is strongest in this situation. This suggestion sits nicely with the finding that WMC predicts performance on tasks such as cross-modal Stroop whereby target-distracter synchronicity is known to modulate interference effects (e.g., Elliott, Cowan, & Valle-Inclan, 1998).

The role of distracter inhibition

In what way is the target-distracter competition resolved? As shown here, and elsewhere (Marsh et al., 2012), the competition appears to be resolved by distracter inhibition (as manifest in a NP effect). This inhibition process protects correct recall from disruption (as shown by the negative correlation between NP and the between-sequence semantic similarity effect in Experiment 2). Interestingly, the inhibition process itself can, however, be associated with an overhead cost as the magnitude of the between-sequence semantic similarity effect was positively correlated with the NP effect in Experiment 3, but only when individual differences in WMC (and thus the ability to inhibit the distracters) were statistically accounted for. At the same time, higher WMC was associated with greater NP when the distracters were high output dominant (and thus competitors for recall). Higher WMC was also associated with a smaller between-sequence semantic similarity effect, both in the presence of distracter inhibition (Experiments 1, 2 and 3) and in the absence of distracter inhibition (Experiment 4).

Taken together, this complex pattern of results suggests that the inhibition process that protects from distraction, can itself impair recall: Moreover, the results also show that inhibition it is not the only mechanism underpinning the between-sequence semantic similarity effect since the between-sequence semantic similarity effect and NP sometimes appear unrelated to one another. The findings reported here, however, are consistent with those of many other studies that have failed to find a correlation between the magnitude of a concurrent distraction and the magnitude of NP (e.g., Driver & Tipper, 1989; Stolzfus, Hasher, Zacks, Ulivi, & Goldstein, 1993). One possibility why NP and the between-sequence semantic similarity effect are not always related is that the between-sequence semantic similarity effect is a composite of at least two mechanisms: The competition itself (if it is not inhibited) and an overhead-of-successful-inhibition of the competition. High-WMC individuals resolve the competition through more successful inhibition of distracters, but have to pay the cost of this inhibition – as revealed by the NP effect. Low-WMC individuals, in contrast, are less successful in inhibiting the competition. Failure-to-inhibit the competition—which impacts on low-WMC individuals in particular—could result in blocking of the retrieval access for targets (Anderson, 1983; Mensink & Raaijmakers, 1988; Rundus, 1973).

Evidence for the role of distracter inhibition in semantic auditory distraction is further reinforced by the intrusion analysis of Experiments 1 and 4. Search processes are inevitably going to operate across a semantic space when retrieving categorized lists and, therefore, the presence of semantically-related distracters will impede this process (Unsworth & Brewer, 2010a, 2010b; Unsworth & Engle, 2007). Consistent with this observation, the intrusion analysis of Experiment 1 shows that the selection processes of low-WMC individuals are less efficient than that of high-WMC individuals, especially when targets and distracters are synchronously presented. This is evidenced by the more frequent presence of (low-dominant) semantically-related distracters in the memory search set of low-WMC individuals and their greater susceptibility to low-dominant intrusions in Experiment 4. Of interest, WMC predicts the appearance of intrusion errors regardless of whether they are presented synchronously (Experiments 1-4) or asynchronously (Experiment 1) with the target words or during a retention interval (Beaman, 2004). The requirement for such selection processes are clearly accentuated when target and distracters are presented synchronously and hence are simultaneously activated. On an inhibition selection view, distracter inhibition during the selection process at study may prevent the distracters from being fully encoded, thus preventing them from coming to mind during test (constraints on access). An alternative view is that selection processes have an influence at test by, for example, isolating the distracter from the temporal context of the target list during recall (i.e., output-monitoring), either of which would have a direct impact upon correct recall. The dissociation between constraints on access and monitoring at output fits with the distinction between "back-end" and "front-end" monitoring processes. Back-end control mechanisms such as the distinctiveness heuristic (Dodson & Schacter, 2002) or recollection rejection (Brainerd, Reyna, Wright, & Mojardin, 2003) operate subsequent to (covert) retrieval but before output to assess the appropriateness of outputting a given item (e.g., Halamish, Goldsmith, & Jacoby, 2012). Once (covertly) retrieved, an item—or its associated features—is evaluated to determine whether it can be positively identified as a target or an intrusion (e.g., an item presented as a distracter; Budson et al., 2005). Recent evidence suggests that discriminatory cues may be used at retrieval when under distraction because varying the physical similarity between distracters and targets affected the appearance of both false and correct recalls in a semantic distraction task (Beaman, Hanczakowski, Hodgetts, Marsh, & Jones, 2013). On the other hand, front-end control mechanisms operate by focussing retrieval such that it is mainly information from the desired source that comes to mind during test (e.g., Jacoby et al., 2005). Front-end control mechanisms, therefore, have a similar action to inhibitory mechanisms which prevent the erroneous encoding of distracters such that they do not come to mind during test.

According to a taxonomy proposed by Hasher, Zacks, and May (1999), inhibition can occur at three distinct stages along the information processing chain: Access (at the perceptual stage), deletion (at a stage subsequent to representations entering the focus of attention) and restraint (occurring during the response output processing level). The access function prevents goal-irrelevant information from gaining access to working memory. Conway et al.'s (2001) finding that low WMC participants were more likely to hear their name, and make shadowing errors at the time their name was presented, in an unattended channel in dichotic listening, suggests that such participants failed to prevent inappropriate access (Redick et al., 2007). We argue that the synchronicity manipulation affects the access stage in our Experiment 1 also, with lower WMC participants being unable to prevent related distracters from being processed when in phase with distracters (cf. Sörqvist et al., 2010). Feasibly, the NP result (Experiments 2 and 3) could be a consequence of inhibition occurring at any one of the three stages (access, deletion, and restraint), however. We cannot determine whether or not NP reflects a consequence of distracter inhibition at an early processing stage within which the automatic processing of words is rapidly inhibited (Sörqvist, Stenfelt et al., 2012), whether it occurs later at response production (e.g., Hutchinson, 2011; Kane & Engle, 2003; Long & Prat, 2002). However, notwithstanding our inability to pinpoint the stage of inhibition in semantic auditory distraction, the results are consistent with the idea that inhibition is impoverished in individuals with low WMC (e.g., Gunter, Wagner, & Friederici, 2003; Sörqvist, Stenfelt et al., 2012), and there is now evidence from the retrieval-induced forgetting context (Anderson et al., 1994) that deficits in inhibition of those members of the same category which are in direct competition with targets for retrieval are associated with low WMC (Aslan & Bäuml, 2011; Mall & Morey, 2013).

Alternative accounts

Although we suggest that our results reflect inhibition, alternative non-inhibitory accounts of the results may be possible. For example, one candidate hypothesis is that the NP effect is underpinned in part by source confusion. Within our study, NP is indexed by poorer recall performance for items ignored in the context of a preceding prime trial and completely novel words that were not presented in that earlier context. That the items on the ignored repetition probe trials have two contexts associated with them; being experienced on the preceding prime trial as distracters and then as novel words during the probe trial, could create a source confusion and/or response output bias[2]. For example, retrieval of an item on the ignored repetition probe trial may carry with it source modality information that would identify the item as a distracter on the previous prime trial. Unless participants become aware that all of the distracters presented at prime are thereafter presented in the ignored repetition probe trials, they could withhold these items. Such response-withholding would only operate during the ignored repetition probe trials since the distracters presented during prime in the control probe trials are never presented as targets. However, two lines of evidence appear to rule out an explanation based on source confusion. First, low output-dominant items experienced as distracters at prime are better remembered during the ignored repetition condition than items experienced for the first time at probe (see Experiment 4 within the current paper and Experiment 2 within Marsh et al., 2012) despite the fact that the low-dominant items have two contexts associated with them. Second, distracters that are categorically-unrelated to the items experienced at prime, enjoy facilitation in recall during the ignored repetition probe trials (see Marsh et al., 2012, Experiment 3). Again, these items are associated in two contexts and could, feasibly, create source-monitoring difficulties.

Similarly, an alternative explanation for the apparent WMC differences is that high WMC individuals are superior at monitoring their output at test recognizing that, in fact, some of the items that they generate are intrusions. For example, Unsworth and Brewer (2010b) in the context of an output-editing task—whereby participants are encouraged to speak aloud any items that come to mind during test—found that individuals with high, as compared with low, WMC were better at monitoring their output and indicating that the false recalls they generated were intrusion errors despite the fact that they produced the same amount of intrusions as low-WMC participants. The enigma here is that if high-WMC individuals are better at inhibiting semantically related items at the front end—as the inhibition view suggests—then low-WMC individuals should generate more intrusions than high-WMC individuals during test regardless of whether those items are covertly generated or overtly produced (as is the case with the output-editing technique).

With these details in mind, could the results of our current study be attributable to differences in output-monitoring? Perhaps the most decisive argument against this notion is the consistent correlation between WMC and the NP magnitude whereby high-WMC individuals are more susceptible to the NP effect. Under the assumption that NP is a result of source/output-monitoring, we may reach the conclusion that high-WMC individuals have poorer source/output-monitoring abilities, which is in direct contradiction to the findings of Unsworth and Brewer (2010b). On the other hand, under the assumption that the NP effect is a result of distracter inhibition, it is easier to reconcile why high-WMC individuals are actually more impaired when previous distracters become targets. Moreover, we suggest that there are critical differences between our studies and those of Unsworth and Brewer (2010b) that raise doubt that the results observed here reflect differences in source/output-monitoring. One crucial difference between our study using the semantic auditory distraction paradigm, and that of Unsworth and Brewer (2010b), is that the primary source of interest in the context of semantic auditory distraction are intrusion errors that reflect external-external source confusions: False recall of related, spoken distracters (Marsh et al., 2008). Within the Unsworth and Brewer (2010b) study, the intrusions generated by the participants were primarily internal-external source monitoring errors (probably generated by the participants through automatic or deliberate semantic activations). When prior-list intrusions were considered within Unsworth and Brewer's (2010b) study, differences still arose during the externalised free recall procedure. Since prior-list intrusions are external-external source confusions (those items were previously experienced in the context of previous lists), it is possible that WMC modulates intrusions that originate from an external origin (external-external source confusions) to a greater extent than those from an internal origin (internal-external source confusions). Indeed, like Unsworth and Brewer (2010b), in our analysis of prior-list intrusions within the control probe condition—not contaminated by the presence of related distracters at prime—we also found that low WMC participants were more susceptible to prior-list intrusions (Experiments 2 and 4). This suggestion that WMC differentially modulates intrusions that originate from an external origin (external-external source confusions) as compared with an internal origin (internal-external source-confusions) is admittedly speculative and coupled with a comparison with internal-internal source confusions, should be the subject of further inquiry. Finally, another crucial difference between the current study and that of Unsworth and Brewer (2010b) is that targets within the current study were categorically-related to one another, whereas the list items within the study of Unsworth and Brewer (2010b) were common nouns but unrelated to one another. It is possible that the differences in WMC become more pronounced when relatively rich semantic processing occurs (cf. Rosen & Engle, 1997).

Another indication that false recall might be modulated by superior front-end monitoring, rather than output-monitoring processes, in individuals with high WMC comes from research concerning the modality effect in false recall (greater false recall with auditory as compared with visual presentation written recall). Smith and Engle (2011) found that the modality effect was apparent in individuals with high WMC but absent for those with low WMC. The relevance here is that the modality effect still arises when output-monitoring is disengaged by adopting an inclusion recall instruction (Hege & Dodson, 2004; Hunt, Smith, & Dunlap, 2011). Inclusion instructions require participants to recall study items as well as any other related items that come to mind during test. This procedure requires disengagement of post-access monitoring and typically leads to more critical intrusions than compared to a standard free recall test. Since the modality effect survives inclusion recall instructions it cannot simply be explained by output-monitoring processes. Taken together with the failure to observe a modality effect with low WMC, these results indicate that WMC may be associated with superior front-end control processes as well as back-end monitoring processes, at least in the context of associative lists (cf. Unsworth & Brewer, 2010b).

Conclusions

Although additional work is necessary to support such a view, it is possible that the WMC and the intrusion/distracter-inhibition relationship are more pronounced for intrusions of an auditory origin. This would certainly cohere with recent evidence that WMC is related to the ability to "gate out" auditory distracters at early levels of analysis (Sörqvist, Stenfelt et al., 2012). Moreover, recent evidence (Marsh, Sörqvist, & Hughes, 2013) suggests that externally-induced task-engagement (overlaying targets with visual noise; cf. Hughes et al., 2013) reduced the intrusiveness of distracters whilst, crucially, leaving the number of control intrusions (that were not part of the speech stream and therefore internal-external source-monitoring errors) unaffected. Moreover, when participants were instructed to use inclusion recall whereby they are instructed to recall any visual targets and any other related items that came to mind during test (Hege & Dodson, 2004; Hunt et al., 2011), more intrusions were generated overall but the same pattern emerged: Fewer distracters were generated in the high task-engagement condition. Since output-monitoring is disengaged with inclusion recall, these data indicate that the task-engagement manipulation benefitted front-end monitoring presumably by inhibiting the distracters during study such that they did not come to mind during test. Notably, this is also consistent with the results of our Experiment 1 which showed that the temporal contiguity of targets and distracters was an important determinant of distraction, at least for low-WMC individuals. Therefore, it appears that when the system is more readily engaged by the focal task (via encoding the target), distracter items are more readily suppressed at least amongst individuals with high WMC. Perhaps the key concept here, with regard to the modulation of distraction, is whether there is top-down, moment-to-moment control of the amount of task-engagement (i.e. the notion of increased task-engagement). The relevance of this latter work for the current study is that task-engagement could be whatever those with high WMC do spontaneously and those with low WMC do not (Hughes et al., 2013). Consistent with this notion, low WMC participants typically benefit from task-engagement manipulations whereas high WMC participants do not (Halin, Marsh, Hellman, Hellström, & Sörqvist, 2014). Collectively, these task-engagement findings appear to be more consistent with the notion that WMC differences within the context of auditory distraction are at least partially associated with front-end processes such as inhibition, in addition to monitoring and editing processes during test.

In sum, this paper has illuminated how the human selective attention system strikes a healthy balance between the engageability and flexibility of selectivity (Allport, 1993) by scrutinising further the way in which the obligatory processing of irrelevant auditory information disrupts the free recall of semantic information (Beaman, 2004; Neely & LeCompte, 1999; Marsh et al., 2008). In relating the concept of distracter inhibition to the disruption of on-going task activity, it is suggested that the between-sequence semantic similarity effect may be construed at least in part as an inevitable side-effect of the healthy process of inhibiting candidate, but goal-irrelevant, objects from being selected. Moreover, we have shown that the adaptive inhibitory mechanism that responds to unwanted competition from related memories, carries a negative consequence not just for the later recall of the competing, non-target, memories but for the immediate recall of categorically-related target items (cf. MacLeod & Saunders, 2008). However, we have also shown that without such control, the effects of distraction can be even greater. Therefore, the price of using the inhibitory mechanism is one worth paying given that what the system can potentially gain from the preventing distraction outweighs the cost: Inhibition acts to sustain the engageability of attentional selection by preventing compatible but incorrect information from being used as the basis for responding. Coupled with recent advances within the domain of visual-verbal serial recall (Hughes et al., 2013), this paper has advanced understanding of the character of the (adaptive) mechanisms at work in selective attention. We have demonstrated that irrelevant events are not simply blocked in some general way. Rather, particular features (e.g., semantics, serial order) of distracters are inhibited dependent upon the degree to which distracter features compete for the control of goal-directed action. This extends the findings demonstrating that the relevant features of an internal representation of any object that interferes with the coherent performance of a task will be suppressed (e.g., Frings & Wentura, 2006; Tipper, 1992). For example, Frings and Wentura (2006) required participants either to name word identity or the color of a target at prime whilst ignoring distracters of different identity or color. Ignored repetition displays at probe comprised either the identity of the distracter at prime, or its color. NP was greater for the relevant dimension (identity for the identity task and color for the color task) demonstrating that NP depends on behavioural goals. Therefore, the cognitive processes involved in the focal task, the nature of the inhibitory processing involved in the cognitive control of distraction (e.g., the dimensions of irrelevant material that conflict with the behavioural goals of the current task; Hughes et al., 2013; Marsh et al., 2012), and the cognitive processes involved in obligatory processing of the attended material are all determinants of the degree and character of disruption brought about by the mere presence of auditory to-be-ignored events.

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Author note

John E. Marsh, School of Psychology, University of Central Lancashire, Preston, UK and the University of Gävle, Sweden. Patrik Sörqvist, University of Gävle, Sweden, Cardiff University, UK, and Linnaeus centre HEAD, Swedish Institute for Disability Research, Linköping University, Sweden. Helen M. Hodgetts, École de psychologie, Université Laval, Québec, Québec, Canada, and the Department of Applied Psychology, Cardiff Metropolitan University, Cardiff, UK. C. Philip Beaman, University of Reading, Reading, UK. Dylan M. Jones, School of Psychology, Cardiff University, UK. Dylan M. Jones is also adjunct Professor at the Department of Psychology at the University of Western Australia. The research reported in this paper was supported by an ESRC grant (RES-062-23-1752) awarded to C. Philip Beaman and Dylan M. Jones, a Swedish Research Council grant (2010-2042) and by an ENNAH grant awarded to Patrik Sörqvist. We thank Vicky Stenner, Sonia Packwood, Jennifer Daffin, Melissa Barker, Victoria Smith, and Zofia Mannings for help with data collection and scoring. We also thank Susanne Mayr for useful discussions concerning this manuscript. Correspondence can be addressed to John E. Marsh, University of Central Lancashire, Preston, United Kingdom. Email may be sent to jemarsh@uclan.ac.uk.

Footnotes

[1] The comparison between the two correlation coefficients is calculated by taking the difference between the Fisher z-transformed coefficients and multiplying this difference with an expression that takes the number of participants and the correlation amongst the two predictor variables into consideration.

[2] We thank Susanne Mayr for pointing out this possibility.

Figure captions

Figure 1. The figure shows the means for proportion correct recall (panel A) and the means for intrusions (false recall; panel B) in the four experimental conditions. Error bars are standard error of means.

Figure 2. The figure shows the relationship between the magnitude of the between-sequence semantic similarity effect and operation span scores with synchronous presentation (panel A) and with asynchronous presentation (panel B) of targets and distracters (z-values are presented for both variables).

Figure 3. The figure shows the relationship between the mean number of intrusions caused by speech (intrusions in the related target-distracter relation condition minus intrusions in the unrelated condition) and operation span scores with synchronous presentation (panel A) and with asynchronous presentation (panel B) of targets and distracters (z-values are presented for both variables).

Figure 4. Schematic of the basic experimental design. At trial N, visual to-be-recalled items are presented, all drawn from the same semantic category. Auditory distracter words are presented concurrently with the to-be-recalled words. The auditory words either belong to the same semantic category as the to-be-recalled words (related prime trials) or to a different category (unrelated prime trials). At trial N+1, no auditory items were presented. Visual to-be-recalled items at trial N+1 were either identical to the auditory items from trial N that were semantically related to the to-be-recalled items at trial N (distracter-repetition trials) or the visual items at trial N+1 were from the same semantic category as visual items at trial N (control condition).

Figure 5. The figure shows the relationship between the magnitude of the between-sequence semantic similarity effect and the magnitude of the negative-priming effect in Experiment 2. The data points are z-values.

Figure 6. The figure shows the relationship between the operation span (working memory capacity) scores and the magnitude of the negative priming (NP) effect in Experiment 2. Larger values on the y-axis represent larger NP effects. The data points are z-values.

Figure 7. The figure shows the relationship between the operation span (working memory capacity) scores and the magnitude of the between-sequence semantic similarity effect in Experiment 2. The data points are z-values.

Figure 8. The figure shows the partial relationship between the magnitudes of the between-sequence semantic similarity effect and the negative priming effect in Experiment 3 wherein the variance explained by individual differences in working memory capacity has been statistically removed. The data points are z-values.

Figure 9. The figure shows the relationship in Experiment 4 between the magnitude of the between-sequence semantic similarity effect and individual differences in working memory capacity. In this case, distracters were low-output dominant and targets were high-output dominant. The data points are z-values.

Figure 1

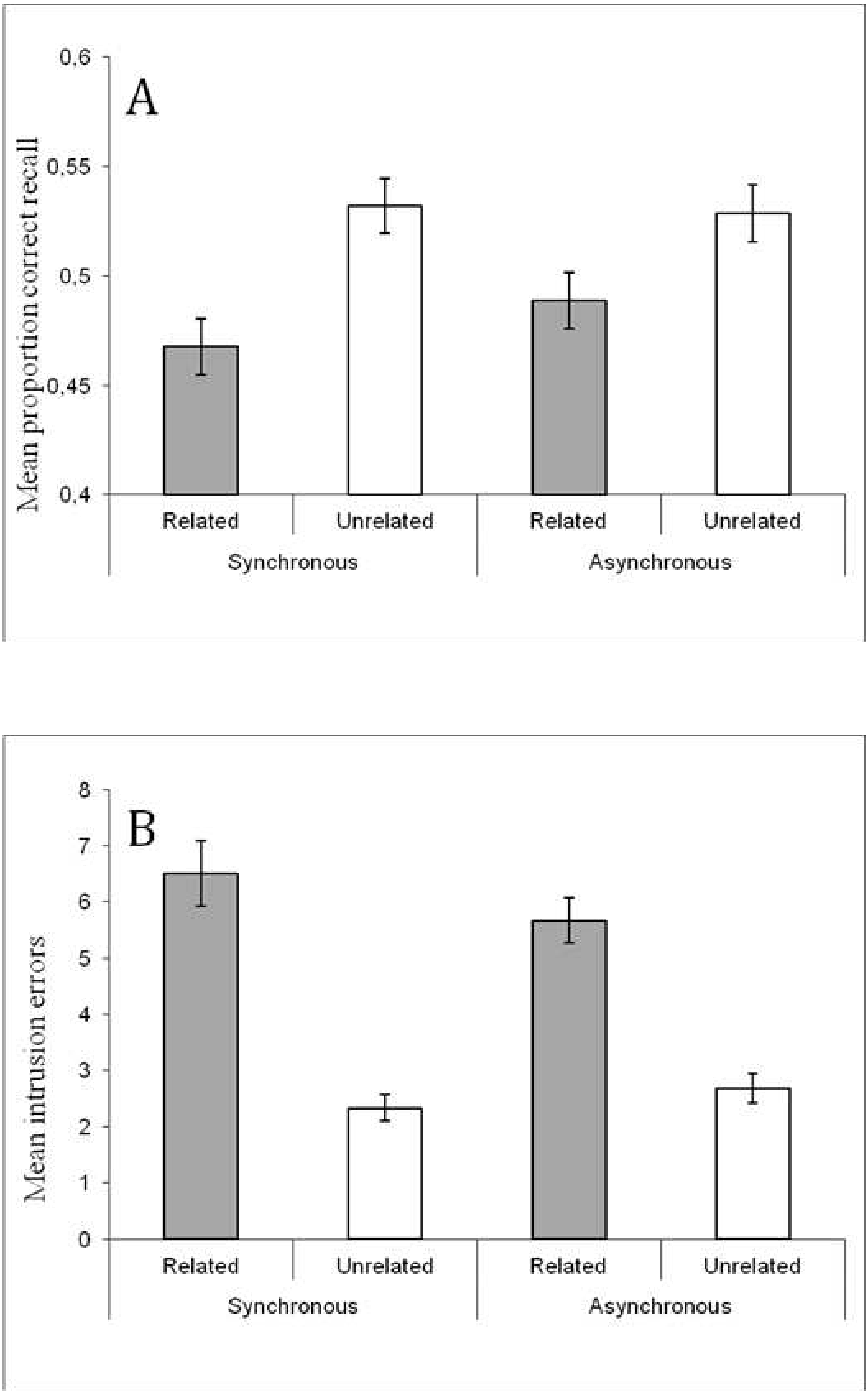
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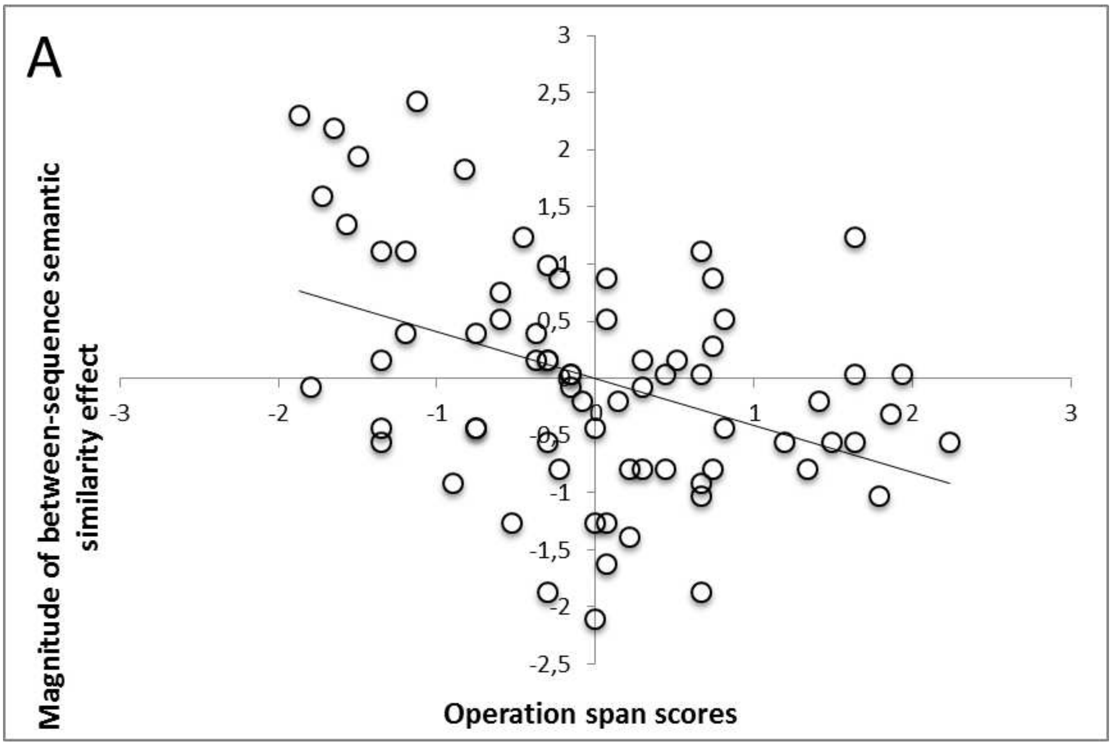
Figure 2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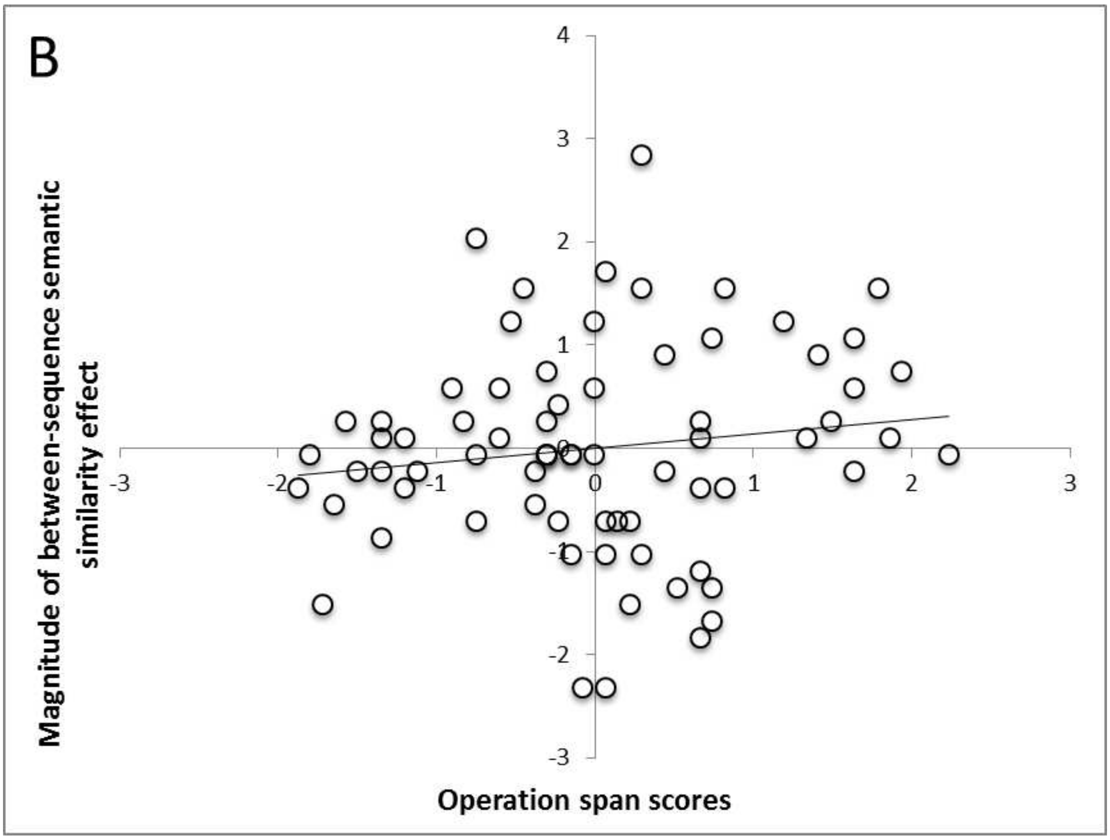
Magnitude of between-sequence semantic similarity effect
Operation span scores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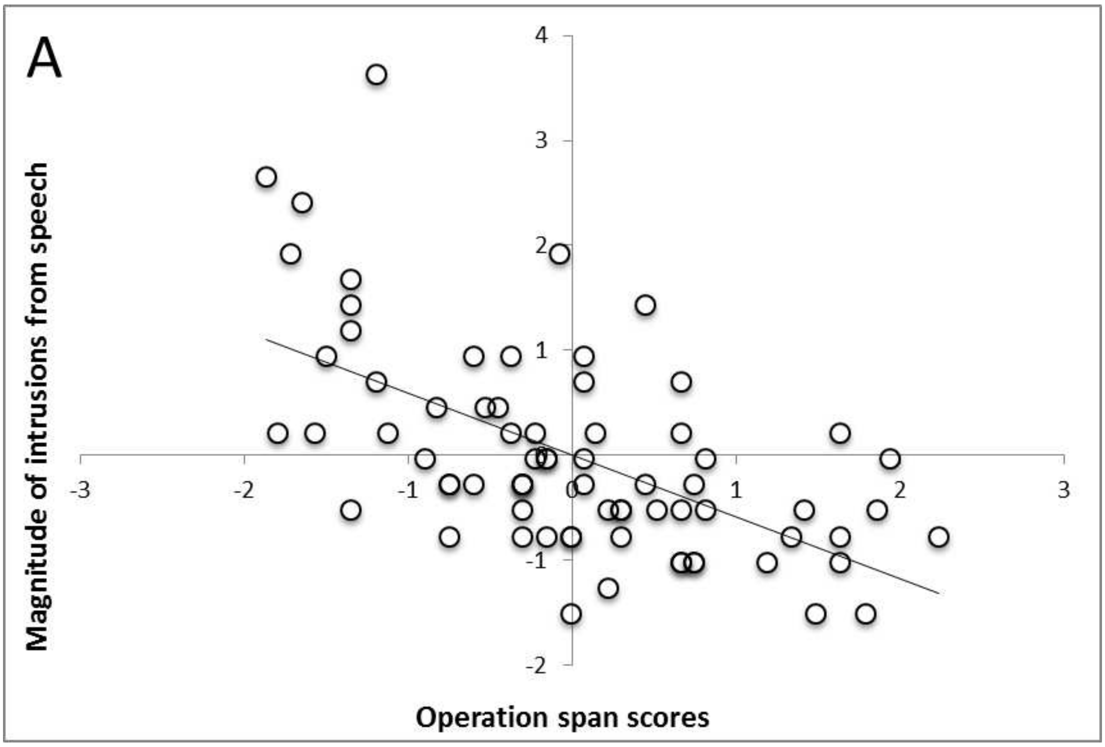
Magnitude of between-sequence semantic similarity effect
Operation span scores

Figure 3


A
Magnitude of intrusions from speech
Operation span scores
4
3
2
1
-1
-2
-3
-2
-1
0
1
2
3

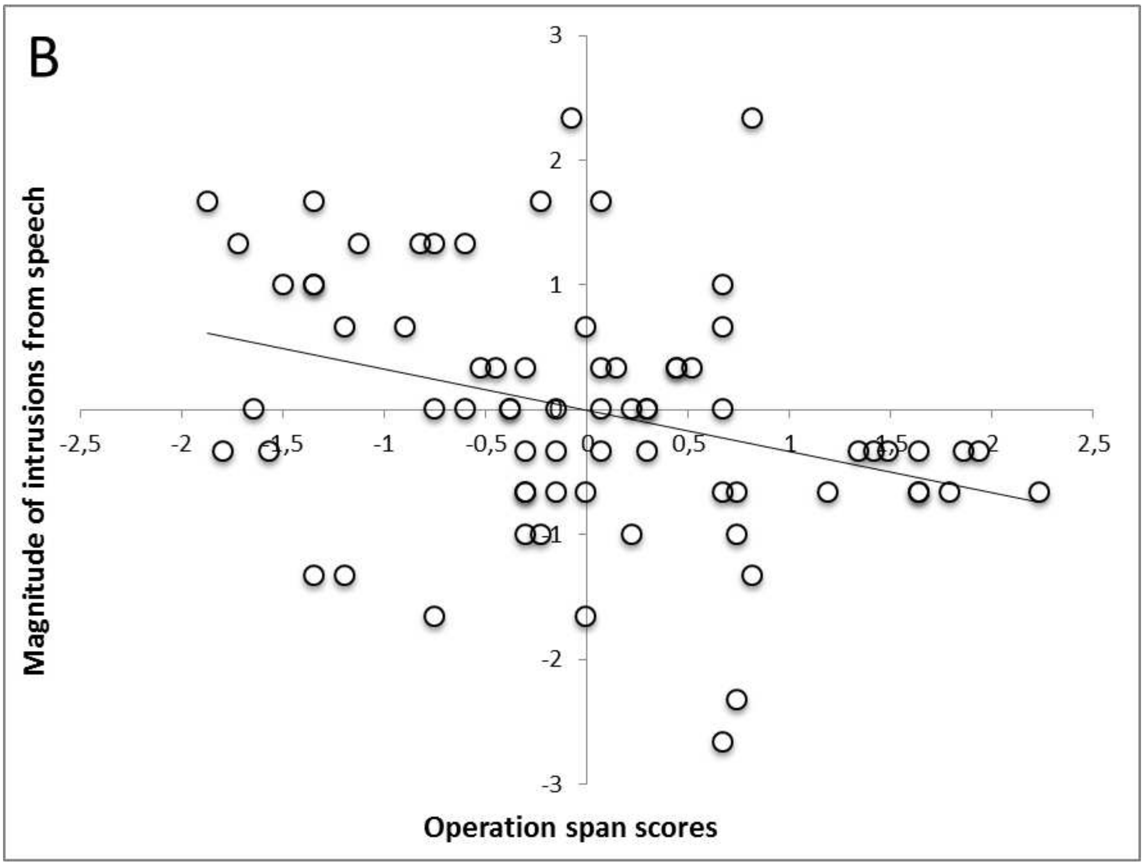

B
Magnitude of intrusions from speech
Operation span scores
3
2
1
-1
-2
-3
-2,5
-2
-1,5
-1
-0,5
0
0,5
1
1,5
2
2,5

Figure 4

Trial *n* (prime)

To-be-recalled items:

Visual presentation of 15 words drawn from the same semantic category

Auditory presentation:

15 spoken words drawn from the same category as the to-be-recalled words (related prime trial)

Or

15 spoken words drawn from a different semantic category (unrelated prime trial)

Trial *n*+1 (probe)

To-be-recalled items:

Visual presentation of the same 15 spoken distracter words that were semantically related to the to-be-recalled words on trial *N* (distracter-repetition probe trial)

Or

Visual presentation of 15 new items taken from the same category as the to-be-recalled items on trial *N* (control condition)

Figure 5

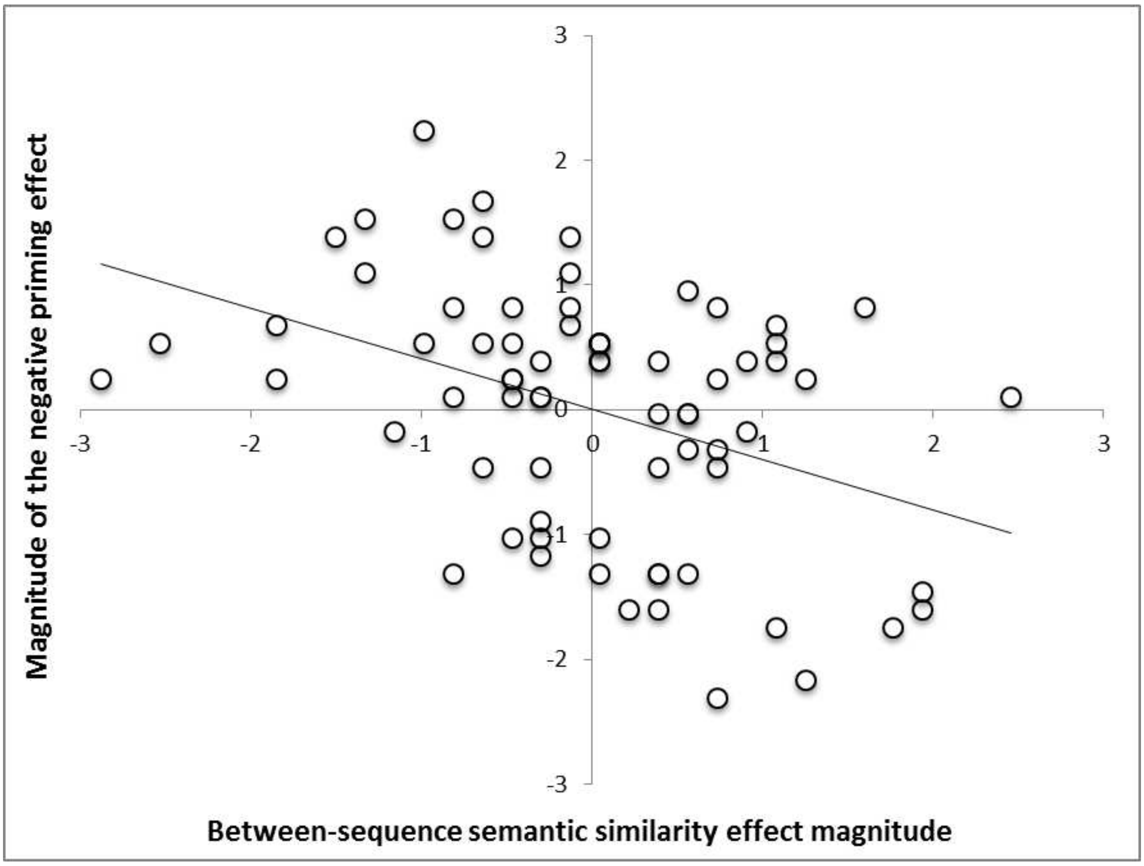

Magnitude of the negative priming effect
Between-sequence semantic similarity effect magnitude
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

Figure 6

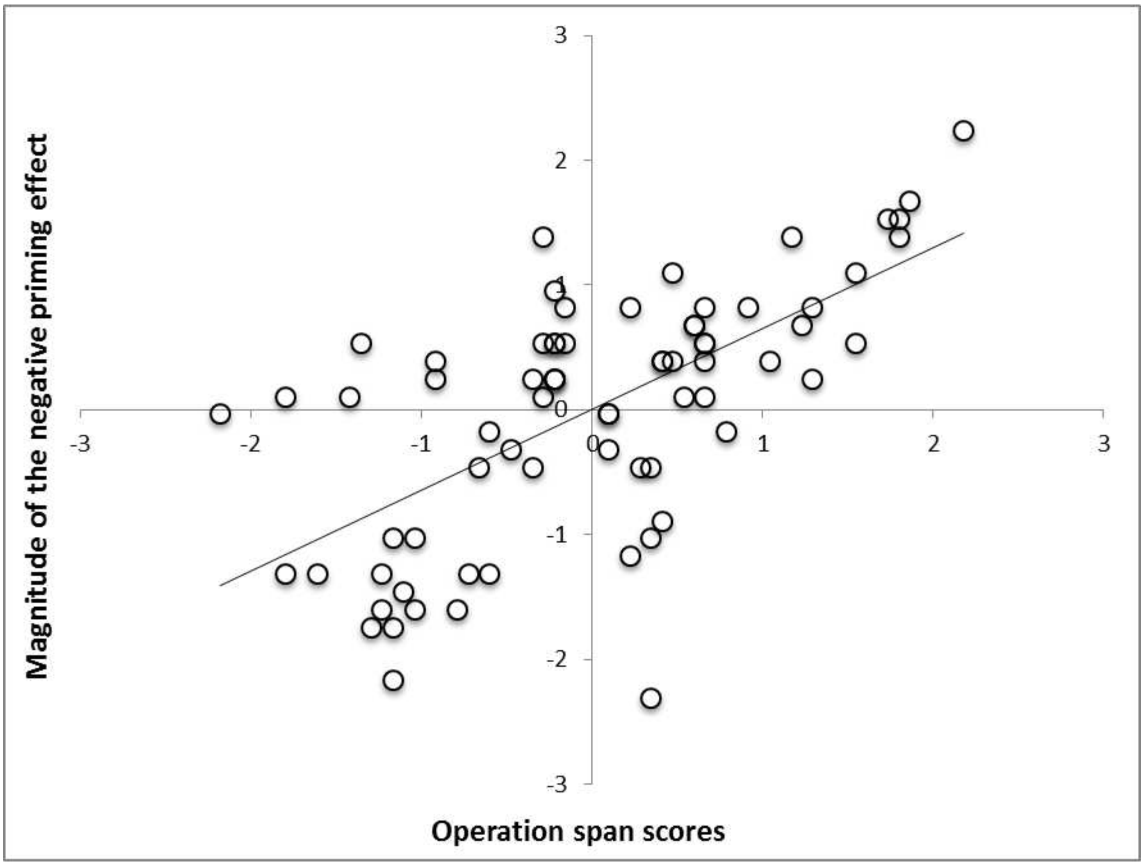

Magnitude of the negative priming effect
Operation span scores
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

Figure 7

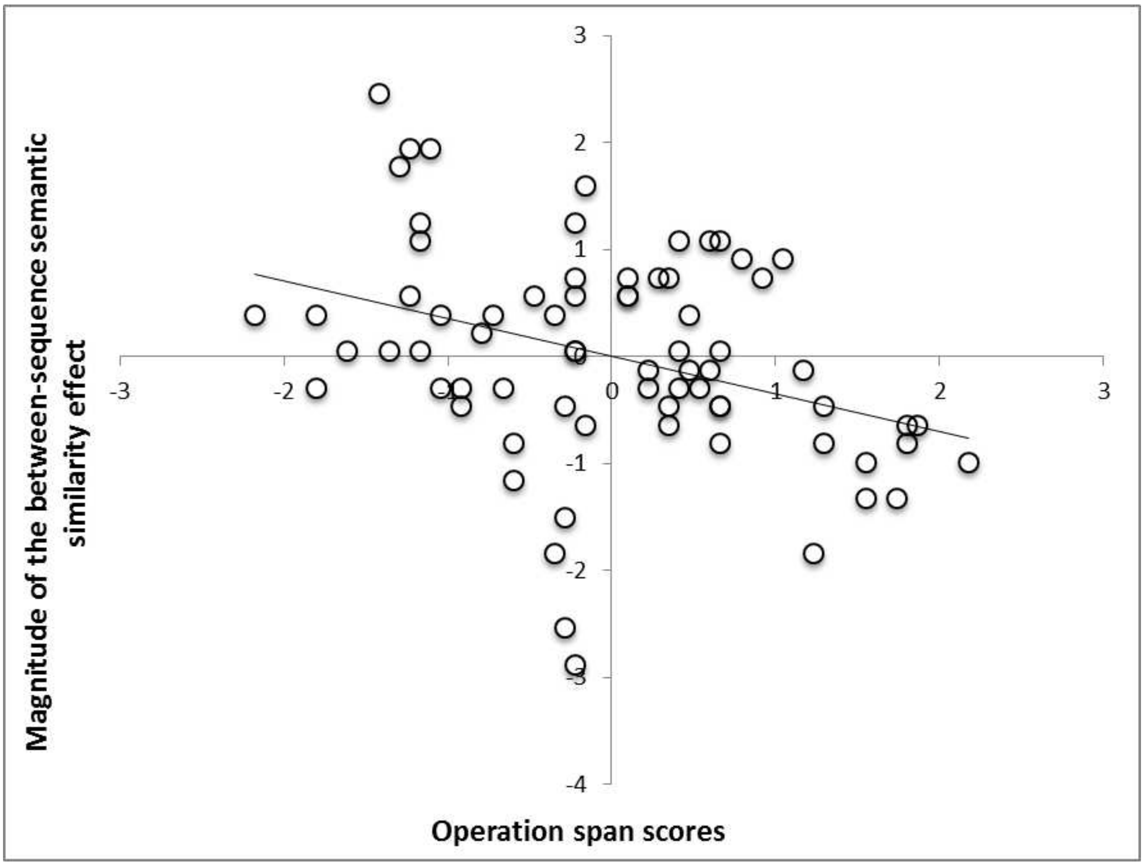

Magnitude of the between-sequence semantic similarity effect
Operation span scores
3
2
1
0
-1
-2
-3
-4
-3
-2
-1
0
1
2
3

Figure 8

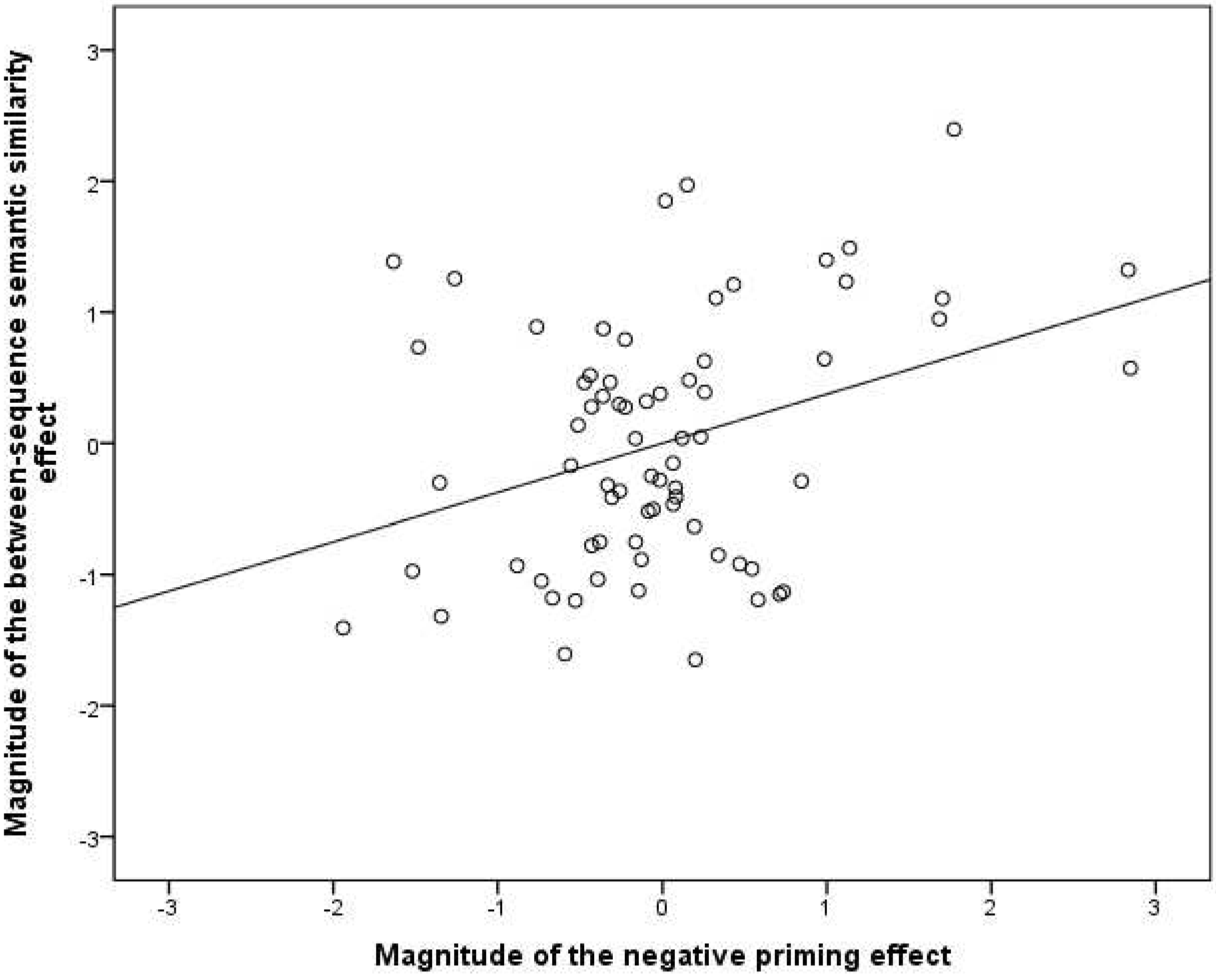

Magnitude of the between-sequence semantic similarity effect
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
Magnitude of the negative priming effect

Figure 9

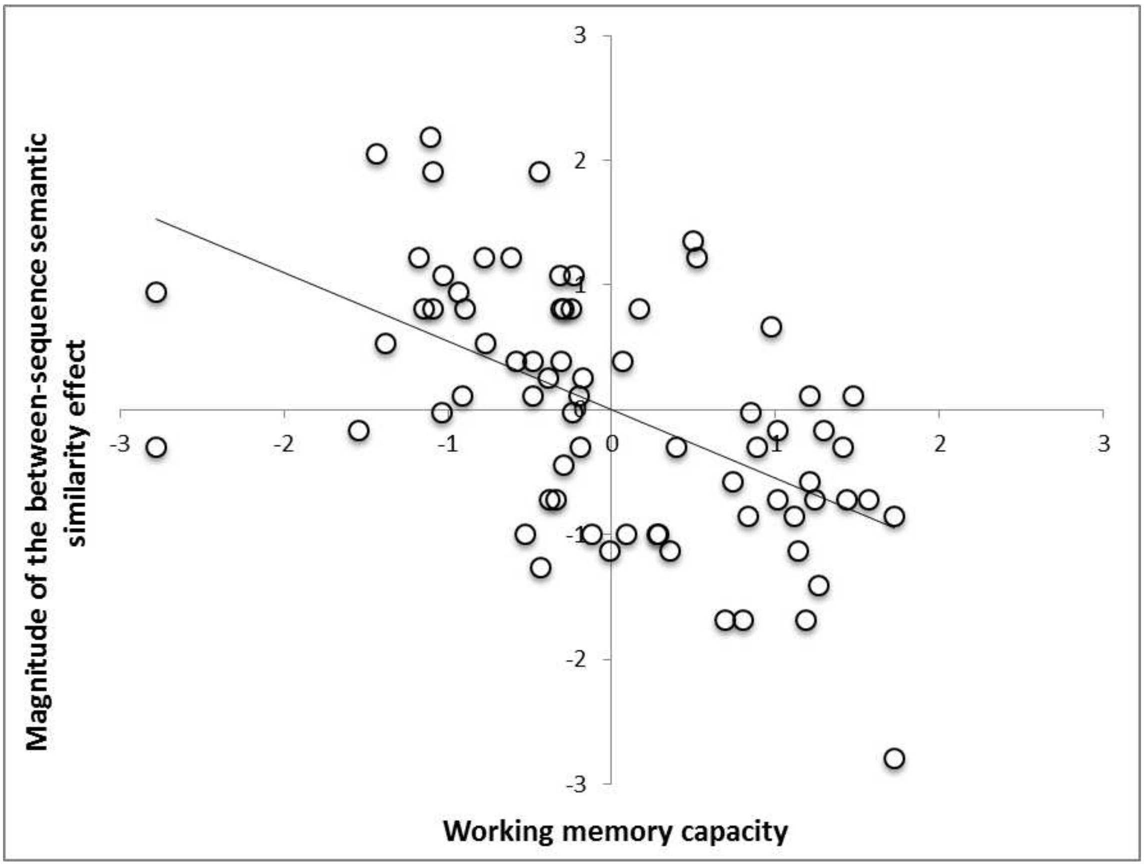

Magnitude of the between-sequence semantic similarity effect
Working memory capacity
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3

Table 1

The table shows mean correct recall for the between-sequence semantic similarity (BSSS) effect wherein the experimental condition is auditory presentation of distracters semantically-related to the to-be-recalled items, and the control condition is auditory presentation of distracters from a different category; and the negative priming (NP) effect wherein the experimental condition is recall of items at trial N+1 that acted as distracters semantically-related to to-be-recalled items on trial N, and the control condition is recall of items at trial N+1 that are members of the same semantic category as to-be-recalled items on trial N but that did not act as distracters.

	Condition								
	Experimental		Control		Difference				
Effect	M	SD	M	SD	M	SD	t	df	p
	Experiment 2								
BSSS	0.39	0.07	0.43	0.06	0.04	0.04	6.56	71	< .001
NP	0.42	0.06	0.44	0.07	0.02	0.05	3.94	71	.014
	Experiment 3								
BSSS	0.39	0.09	0.45	0.09	0.06	0.05	10.03	70	< .001
NP	0.49	0.08	0.52	0.10	0.02	0.06	3.14	70	.002
	Experiment 4								
BSSS	0.48	0.13	0.50	0.11	0.02	0.02	2.56	71	.013
NP	0.39	0.09	0.37	0.09	-0.02	0.02	3.85	71	< .001

Note: the difference scores for the BSSS effect are obtained by taking the experimental condition minus the control condition, and the other way around for the

NP, so that positive values always represent large effects. Inferential statistic is a one-sample t on the difference scores with zero as comparison value.

Table 2

The table shows mean number of distracter intrusions for the semantically-related (Experimental) and semantically-unrelated (Control) prime trials, and prior-list intrusions for the ignored repetition (Experimental) and control probe (Control) conditions of Experiments 2-4.

	Condition								
	Experimental		Control		Difference				
Intrusion Type	M	SD	M	SD	M	SD	t	df	p
Experiment 2									
Distracter	4.22	2.55	1.58	1.63	2.64	2.30	9.75	71	< .001
Prior List	2.54	1.97	2.99	1.70	-0.44	1.86	-2.03	71	.046
Experiment 3									
Distracter	3.58	3.33	1.37	1.26	2.21	3.01	6.22	71	< .001
Prior List	1.82	1.29	2.25	1.86	-0.43	1.66	-2.20	71	.031
Experiment 4									
Distracter	1.53	1.23	0.56	0.77	0.97	1.21	6.82	71	< .001
Prior List	2.35	1.71	3.04	2.74	-0.69	2.67	-2.20	71	.031

Note: inferential statistic is a one-sample t on the difference scores with zero as comparison value.