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Facilitation and interference in naming: A consequence of the same learning process?

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Abstract

Our success with naming depends on what we have named previously, a phenomenon thought to reflect learning processes. Repeatedly producing the same name facilitates language production (i.e., repetition priming), whereas producing semantically related names hinders subsequent performance (i.e., semantic interference). Semantic interference is found whether naming categorically related items once (continuous naming) or multiple times (blocked cyclic naming). A computational model suggests that the same learning mechanism responsible for facilitation in repetition creates semantic interference in categorical naming (Oppenheim, Dell, & Schwartz, 2010). Accordingly, we tested the predictions that variability in semantic interference is correlated across categorical naming tasks and is caused by learning, as measured by two repetition priming tasks (picture-picture repetition priming, Exp. 1; definition-picture repetition priming, Exp. 2, e.g., Wheeldon & Monsell, 1992). In Experiment 1 (77 subjects) semantic interference and repetition priming effects were robust, but the results revealed no relationship between semantic interference effects across contexts. Critically, learning (picture-picture repetition priming) did not predict semantic interference effects in either task. We replicated these results in Experiment 2 (81 subjects), finding no relationship between semantic interference effects across tasks or between semantic interference effects and learning (definition-picture repetition priming). We conclude that the changes underlying facilitatory and interfering effects inherent to lexical access are the result of distinct learning processes where multiple mechanisms contribute to semantic interference in naming.

Keywords

language production; semantic interference; learning; priming; individual differences

1. Introduction

Whether it is throwing a perfect curveball, learning multiplication tables, or remembering where we parked the car, our abilities are enhanced with practice. Repetition improves

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performance, as each time we repeat an action we update our knowledge by strengthening connections for more efficient access in the future (i.e., incremental learning). These changes are fundamental to performance across many domains including perceptual learning (e.g., Petrov, Dosher, & Lu, 2005), belief updating (e.g., Nassar, Wilson, Heasly, & Gold, 2010), and language adaptation and learning (for a review see Chang, Janciauskas, & Fitz, 2012). Generally, we consider these changes to be positive effects, as they improve our future performance. However, there are negative consequences of learning. For example, if after repeatedly parking in one space we change parking locations, we may find ourselves wandering back to the original space, even though it is the wrong location, because we "learned" it so well. Thus, although repetition and learning through practice generally engender positive consequences, these consequences hurt us if we need to change our actions.

Language processes follow this same pattern, as our ability to produce speech quickly and accurately depends on our prior language production experiences. For example, naming a previously named picture results in faster and more accurate naming (repetition priming, e.g., Mitchell & Brown, 1988). Repetition priming results from a speech production system that uses each naming event as a "learning experience" to ensure future efficiency and accuracy (e.g., Mitchell & Brown, 1988, Oppenheim, Dell, & Schwartz, 2010). However, all priming effects are not facilitatory, as naming pictures primed by semantically related items results in longer naming latencies (e.g., Brown, 1981). This semantic interference effect is thought to reflect the same long-lasting learning experience that facilitates naming (Oppenheim et al., 2010), since interference occurs regardless of whether semantically related pictures are presented consecutively (blocked/blocked cyclic naming; Abdel Rahman & Melinger, 2007, 2010; Belke, 2008; Belke, Meyer, & Damian, 2005; Damian & Als, 2005; Damian, Vigliocco, & Levelt, 2001; de Zubicaray, Johnson, Howard, & McMahon, 2014; Kroll & Stewart, 1994; Maess, Friederici, Damian, Meyer, & Levelt, 2002; Meinzer, Yetim, McMahon, & de Zubicaray, 2016; Navarrete, Del Prato, & Mahon, 2012; Schnur, Schwartz, Brecher, & Hodgson, 2006; Vigliocco, Lauer, Damian, & Levelt, 2002) or non-consecutively, with anywhere from two to eight intervening semantically unrelated items (i.e., continuous naming; e.g., Belke, 2013; Canini et al., 2016; Howard, Nickels, Coltheart, & Cole-Virtue, 2006; Navarrete, Mahon, & Caramazza, 2010; Runnqvist, Strijkers, Alario, & Costa, 2012; Schnur, 2014). The aim of this study was to test the assumptions of Oppenheim et al.'s (2010) computational model of language production (henceforth, Dark Side Model) which implements both positive and negative effects of the "learning experience" in the same way when naming and successfully simulates naming performance in blocked cyclic and continuous naming. Testing whether interference in naming across different contexts is similar and arises from a learning mechanism will provide insight about the facilitatory and interfering processes inherent to lexical access as well as how these processes reflect the general and ubiquitous cognitive principle of learning.

Semantic interference effects in naming are widely replicated across two different types of naming contexts. In blocked cyclic naming, pictures appear either in semantically related (e.g., *cat, dog, bird*) or unrelated groups (e.g., *cat, truck, lamp*) called blocks for a number of repetitions (cycles), each with a different picture order (e.g., Damian & Als, 2005). Semantically related, as compared to unrelated contexts increase response latencies across the block (semantic *blocking effect*), and the difference in response latencies (Related - Unrelated) increases across cycles (*growth effect*; e.g., Schnur et al., 2006; cf. Belke & Stielow, 2013; Damian & Als, 2005). Overall, performance improves when repeating items (i.e., repetition priming), but this benefit is attenuated in the semantic context. In the continuous naming paradigm, each category exemplar is named once with no two pictures from the same category appearing consecutively, and the position of a picture within its semantic category members is called its ordinal position. Naming times increase linearly across ordinal positions (*ordinal slope effect*), and this increase is unaffected by intervening unrelated items (e.g., Howard et al., 2006; Navarrete et al., 2010; cf. Schnur, 2014). Across both blocked cyclic and continuous naming, repeatedly naming from the same semantic category increases response times, resulting in significant semantic interference.

The computational Dark Side Model (Oppenheim et al., 2010) assumes a learning mechanism underpins word production processes. This mechanism reflects our "learning experience" and operates over the connections between semantic features (e.g., *four legs, fur, tail*) and corresponding lexical representations (e.g., "cat" or "dog"). Repeating a word facilitates naming, as learning strengthens the semantic-to-lexical connections (hereafter, lexical-semantic connections) after correctly producing the name of the intended target. At the same time, the learning mechanism ensures that non-target items sharing semantic features with the named target will not be strong competitors in the future by weakening the lexical-semantic connections to those semantic features they share with the named target. Consequently, naming latencies increase with each additional category item due to previous weakening of some lexical-semantic connections to that item, resulting in the blocked cyclic naming *blocking* and *growth effects* (e.g., Schnur et al., 2006) and the linear *ordinal slope effect* in continuous naming (e.g., Howard et al., 2006). In sum, the learning process both helps and hinders naming performance due to lexical-semantic connection weight changes.

With the assumptions that semantic interference effects in blocked cyclic and continuous naming contexts reflect the same phenomenon, and a learning mechanism drives semantic interference during naming, the Dark Side Model's architecture (Oppenheim et al., 2010) generates two predictions about individuals' performance across semantic interference tasks. First, because individuals vary in their susceptibility to semantic interference (Maess et al., 2002), based on the first assumption, the Dark Side Model predicts that individual variability in the semantic interference effect observed in blocked cyclic naming should pattern with that in continuous naming. As such, when examining individual differences in naming performance, we expect to find significant correlations between semantic interference effects in blocked cyclic and continuous naming. Second, as individuals vary in their learning abilities (e.g., Woltz & Schute, 1993), based on the second assumption, if a learning mechanism underlies the interference effects observed in blocked cyclic and continuous naming, then individual learning mechanism strength should predict performance in both tasks. Therefore, we expect to find significant correlations between individually measured learning mechanism strength and the semantic interference effects in blocked cyclic and continuous naming. Thus, an individual differences approach is a powerful method not only to examine these predictions but also because it has the potential to reveal the processing dynamics of the language system.

Whether the processes behind semantic interference effects in blocked cyclic and continuous naming are served by the same mechanism, and whether this mechanism is the same as that which causes facilitation in repetition priming (as proposed by Oppenheim et al., 2010), to our knowledge has never been empirically tested. Additionally, given that each task differs in how it elicits semantic interference (organization of related items, repetition of items) and differs in the degree to which it recruits working memory resources (Belke, 2008; Belke & Stielow, 2013), there is further question as to whether these tasks are as similar as has been proposed (see also Belke, 2013; Navarrete et al., 2012; Navarrete, Del Prato, Peressotti, & Mahon, 2014; Riley, McMahon, & de Zubicaray, 2015). Understanding whether semantic interference is caused by the same mechanism is important because these paradigms and semantic interference effects in general are used to test theories of the cognitive architecture in language production (e.g., Dell, Oppenheim, & Kittredge, 2008; Rapp & Goldrick, 2000; Levelt, Roelofs, & Meyer, 1999; Schnur et al., 2006), comprehension (e.g., Campanella & Shallice, 2011; Crutch, Connell, & Warrington, 2009; Wei & Schnur, 2016) and deficits in executive control (e.g., Biegler, Crowther, & Martin, 2008; Harvey & Schnur, 2015; Jefferies, Baker, Doran, & Ralph, 2007; Ries, Karzmark, Navarrete, Knight, & Dronkers, 2015; Schnur et al., 2009).

To address these questions, we compared interference effects within individuals across the two semantic interference naming paradigms simulated by the Dark Side Model (Oppenheim et al., 2010) in Experiments 1A, 2A (blocked cyclic naming) and Experiments 1B, 2B (continuous naming). We examined the *blocking* and *growth effects* in blocked cyclic naming as individual measures of semantic interference because both are simulated by the Dark Side Model (Oppenheim et al., 2010) and both are typical measures of semantic interference (e.g., Belke, 2008; Navarrete et al., 2012; Schnur et al., 2006; Schnur et al., 2009). Second, we wanted to test Oppenheim et al.’s (2010) proposal that the mechanism by which lexical-semantic weights are weakened (semantic interference) is the same mechanism which governs connection weight strengthening (facilitation) in repetition priming. In an attempt to best capture individual learning strength at the lexical-semantic level we measured individual learning strength with both a picture-picture repetition priming paradigm (e.g., Cave, 1999; Durso & Johnson, 1979; Woltz & Shute, 1993; Experiment 1C) and a definition-picture repetition priming paradigm (e.g., Wheeldon & Monsell, 1992; Experiment 2C). We then investigated whether an individual’s semantic interference effects were correlated and if the learning measures predicted performance in these tasks.

It is important to note that although there are multiple possible measures of individual learning strength, we chose the picture-picture repetition priming (Exp. 1C) and definition-picture repetition priming (Exp. 2C) tasks as two potential measures of learning under the following rationale. In Experiment 1, we chose to explore picture-picture repetition priming as a measure of learning for two main reasons. First, repetition priming in picture naming (from the first to second naming occurrence) is a well-known and robust phenomenon of learning in word production (cf. Damian & Als, 2005; Oppenheim et al., 2010, Wheeldon & Monsell, 1992). It occurs at all levels of the language system, during visual/conceptual processing (i.e., object recognition, Tulving & Schacter, 1990), as well as during lexical selection, phonological encoding, and articulation (e.g., Barry et al., 2000; Ellis et al., 1996; Francis, Corral, Jones, & Sáenz, 2008; Francis, 2014; van Turennout, Ellmore, & Martin, 2000). Important to the assumption that picture-picture repetition priming reflects the learning which also is hypothesized to occur during blocked cyclic and continuous naming tasks, picture-picture repetition priming effects are not isolated to object recognition processes but also occur at stages specific to word production in magnitudes greater than, and independent of, object recognition (Francis, 2008, p. 575) where selecting the appropriate word for naming is a critical part of this process. Second, repetition priming, i.e., repeating picture names, is one factor in a task simulated by Oppenheim et al. (2010) (i.e., blocked cyclic naming). However, because the effects of picture-picture repetition priming are not isolated to the lexical-semantic system (as is the learning process that is modeled in the Dark Side Model; Oppenheim et al., 2010), in Experiment 2 we investigated individual learning effects using a definition-picture priming task (e.g., Wheeldon & Monsell, 1992). In a definition-picture priming task, subjects produce a name to a definition, and then repeat the same name by naming a subsequent picture. Because the prime and target are not the same visually (a written definition vs. a picture), there is no overlap of visual input processing. As such, this task may better reflect the lexical-semantic learning process as outlined by Oppenheim et al. (2010).[1] We return to a discussion of the merits of picture-picture and definition-picture repetition priming as measures of learning in the General Discussion.

2. Experiment 1

2.1. Method

2.1.1. Subjects—Subjects were 77 native English-speaking Rice University students who received research credit or monetary compensation. All participants gave informed consent in accordance with Rice University's Institutional Review Board. Six participants were removed from further analysis either because of failures of the voice-key to register responses (n = 4) or because their number of errors was outside of group performance (n = 2).

2.1.2. Materials and Procedure—Experiments 1A-1C were completed in different order (Latin square) across participants, and all experiments were completed in one testing session lasting approximately 45 minutes. Time between experiments was minimal, consisting only of the amount of time for the experimenter to close one experiment and give participants instructions for the subsequent.

2.1.2.1. Experiment 1A: Blocked Cyclic Naming: Stimuli were 60 color photographs (12 semantic categories, five exemplars each) from the Bank of Standardized Stimuli (BOSS) (Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010), the standardized set of ecological pictures (Viggiano, Vannucci, & Righi, 2004), the real world normed picture set (Karst, Clapham, & Wessinger, 2009) and online google.com image search (See Appendix A for stimuli for Experiments 1A – 1C). In semantically related blocks, five same category exemplars (comprising one cycle) were presented five times each (one block: five cycles) in a randomized presentation. In unrelated blocks, five pseudorandomly chosen different

[1]We thank an anonymous reviewer for this suggestion.

category exemplars appeared five times each. No more than two blocks of the same condition (related, unrelated) were presented successively.

Before the experiment, participants named each exemplar and were given corrective feedback (following Belke, 2008; Damian & Als, 2005; Damian, Vigliocco & Levelt 2001; Schnur et al., 2006). On each trial, a fixation cross "+" appeared for 1000 ms, then the target appeared for 1600 ms or until the response.

2.1.2.2. Experiment 1B: Continuous Naming: Methods for Experiment 1B and C were identical to Experiment 1A except where noted.

Stimuli were 60 color photographs from 12 semantic categories (different from Experiment 1A), with five from each category.

We followed Howard et al.'s (2006) procedure with the following exceptions. The number of intervening pictures between same category items (lag) was kept consistent (2), following Runnqvist et al. (2012). Twelve semantic categories were used instead of 24 to prevent overlap of categories between Experiments 1A, 1B, and 1C. Category and exemplar order was randomized for each participant (orders written in MATLAB v7.10.0; The MathWorks Inc., 2010; Schnur, 2014).

Participants were not familiarized with the pictures in advance (following Howard et al., 2006; Runnqvist et al., 2012; Schnur, 2014).

2.1.2.3. Experiment 1C: Repetition Priming: Subjects named 90 color photographs not presented in Experiments 1A and 1B (with minimal semantic relationships between stimuli), across two naming sessions, encoding and testing. There was no practice session before the experiment. During encoding, participants named 60 photographs. After a brief break, during testing, participants named 30 photographs from the encoding phase and 30 new items.

2.2. Results

2.2.1 Group Analyses—We excluded RTs faster than 250 ms and outside of three SDs from each subject's mean RT. Further, RTs were removed for trials where the following occurred: omissions, microphone errors, voice key errors (coughing, sneezing, etc.), and naming errors. Errors accounted for 1.8% of the data in Experiment 1A, 15.5% of Experiment 1B, and 14.5% of Experiment 1C. We analyzed RTs using repeated measures ANOVAs in blocked cyclic naming (Exp. 1A) where fixed factors included blocking (related/unrelated), cycle (1–5), and the linear contrast of the interaction between blocking and cycle (the growth effect). In continuous naming (Exp. 1B) fixed effects included the linear contrast across ordinal positions (1–5). Random effects were within-subject (F1) and within-item (blocked cyclic) or within-category (continuous naming, F2). In repetition priming (Exp. 1C), we tested condition (old vs. new items) using paired (by subject, t_1) and unpaired (by item, t_2) t-tests. See Table 1 and Figure 1 for RT results.

2.2.1.1. Experiment 1A: Blocked Cyclic Naming: Naming latencies were significantly longer in the related (651 ms) vs. unrelated (628 ms) condition (*blocking effect:* 23 ms, 95% CI [20–27])[2], replicating previous studies (e.g., Damian et al., 2001), and this difference grew across cycles (*growth effect*) (e.g., Schnur et al., 2006; see Figure 1A).[3]

2.2.1.2. Experiment 1B: Continuous Naming: Naming latencies increased linearly across the five ordinal positions (*ordinal slope*), replicating previous studies (e.g., Howard et al., 2006; Navarrete et al., 2010; Runnqvist et al., 2012; Schnur, 2014). On average, subjects responded approximately 15 ms (95% CI [9.9–20.4]) slower across each ordinal position (see Figure 1B).

2.2.1.3. Experiment 1C; Picture-Picture Repetition Priming: Following Mitchell and Brown (1988), only responses from the testing phase were analyzed. Two items from the testing phase were removed due to high error rates (>50%). Naming latencies were faster for old (780 ms) vs. new items (929 ms), indicative of repetition priming (average effect 149ms, 95% CI [132–166]).

2.2.2. Correlation Analyses—We calculated individual semantic interference magnitudes in blocked cyclic naming (*blocking effect*, *growth effect*) and continuous naming (*ordinal slope*). In repetition priming, individual learning strengths reflected facilitation magnitudes (*learning effect*, see Table 2 for all effect calculations). For each of these interference and repetition priming effects, we examined task reliability using Spearman-Brown correlations. When calculating Spearman-Brown correlations, data are generally divided into two halves using odd and even trials (e.g., Brayfield & Rothe, 1951), and this is how we calculated reliability for the *learning effect* in repetition priming. However, in our study design, cross-task correlations with semantic interference effects necessarily correlate data from different semantic categories. Thus, we determined within task correlations (i.e., reliability) for the semantic interference effects (*blocking effect, growth effect, ordinal slope*) by dividing the data so that each half comprised half of the semantic categories (i.e., six categories each; see Supplemental Material for details).[4] Spearman-Brown internal reliability correlations for the *blocking, growth, ordinal slope* and

[2]The effects in cycle 1 are often different from effects at the following cycles, where some studies report no effects (e.g., Navarrete et al., 2012 Exp. 2) while others report a facilitation effect (e.g., Navarrete et al., 2012 Exp. 1). The interference effect at cycle 1 was marginally significant in our data (6.8ms, 95% CI 1.4–12.3 ms, $t1(70) = 2.52$, $p = .014$, $t2(59) = 1.11$, $p = .27$). There are several explanations in the literature for the lack of semantic interference and/or facilitation at cycle 1 including semantic priming (Damian & Als, 2005), strategic processes (Belke, 2008; Oppenheim et al., 2010), and contamination of baseline effects (Navarrete et al., 2014). We agree with Oppenheim et al. (2010) that strategic processes may best explain these effects, as Belke (2008) found that when a short term memory load was added during blocked cyclic naming, semantic interference was present even on the first cycle, where if semantic priming were occurring, facilitation would be expected instead.

[3]In Figure 1A the maximal growth effect in the blocked cyclic naming task appears between cycles 1 and 3, where interference eventually plateaus in cycles 4 and 5 (cf. Belke & Stielow, 2013). We note that this pattern is not the same pattern for every participant and the individual semantic interference effects for the correlation analyses (see Section 2.2.2.) are dependent on individual effects in naming, where, for example there is a range in the growth effect across the five cycles (13.69 – 28.36 ms/cycle). However, we also examined the blocked cyclic RT condition*cycle effect when excluding the first cycle (following Belke & Stielow, 2013). Both the interaction ($F1(3,210) = 5.70$, $p = .001$, $F2(3,177) = 7.00$ $p < .001$) and the linear contrast ($F1(1,70) = 4.99$, $p = .029$, $F2(1,59) = 4.82$, $p = .032$; 3.0 ms/cycle) were significant. It is a question for future research as to whether the inconsistencies in reported condition × cycle interactions and linear contrasts in blocked cyclic naming (i.e., the growth effect) across studies (reported non-significant interactions in Belke and Stielow (2013) but significant interactions reported in Belke (2008); Navarrete et al., (2012); Schnur et al., (2006)) are due to Type I error (potentially incorrect statistical approaches yielding falsely significant condition × cycle effects) or Type II error (e.g., too few subjects or items to detect the effects).

[4]We thank Gary Dell for this suggestion.

learning effects ranged from .34 – .44 (see Table 3). Subjects displayed a wide range of performance in each of the effects (see Table 4), and with 71 subjects, our power to detect cross-task correlations of a magnitude of $r \geq .30$ was .74 or greater (calculated using G*Power: Faul, Erdfelder, Lang, & Buchner, 2007).[5]

To test the hypothesis that semantic interference arises via the same process in blocked cyclic and continuous naming we correlated across individuals the magnitude of the *blocking* and *growth* effects in blocked cyclic naming (Exp. 1A) with the *ordinal slope* effect in continuous naming (Exp. 1B). No correlation was significant (*p*'s > .40; see Figure 2).

To test the hypothesis that learning underlies the semantic interference effects in blocked cyclic and continuous naming, we correlated subjects' *learning effects* (as measured by the magnitude of repetition priming, Exp. 1C) with the magnitude of their *blocking and growth effects* in blocked cyclic naming, and with their *ordinal slope* effects in continuous naming. No correlation was significant (*p*'s > .22; see Figure 3).[6]

2.3 Discussion

In Experiment 1 we tested the hypothesis that the semantic interference effects in blocked cyclic and continuous naming and the repetition priming effect in picture-picture priming are manifestations of the same learning process. With data from 71 subjects, we found no significant correlations either between the semantic interference *blocking* and *growth effects* of blocked cyclic naming and the *ordinal slope* of continuous naming nor between these effects and the *learning effect* as measured by picture-picture priming. However, while the repetition priming effect from picture-picture priming may be attributed to many processes (e.g., visual input processing, speech production processes, e.g., Francis, 2014), the learning mechanism implemented in the Dark Side Model (Oppenheim et al., 2010) is constrained to lexical-semantic learning. As such, it is possible that we found no correlation between the semantic interference effects and the learning effect in Experiment 1 because our learning measure was influenced by processes outside of lexical-semantic processing. In an effort to better isolate the learning measure to the lexical-semantic level of speech production processing and replicate Experiment 1, in Experiment 2, we used a priming task with no visual overlap between stimuli (i.e., definition-picture priming, e.g., Wheeldon & Monsell, 1992). This task minimizes priming effects from visual input processing, instead isolating these effects to speech production processes only (e.g., semantic, lexical, phonological, and articulatory processes).

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[5]Additionally, we examined both within-task and across-task correlations for outliers using studentized deleted (jackknifed) residuals (Kleinbaum, Kupper, Nizam, & Rosenberg, 2013) and found no outliers using a Bonferroni-corrected critical value to control for multiple comparisons.

[6]As there is debate about the nature of cycle 1 performance in the blocked cyclic naming task (see footnotes 1 and 2), we also correlated the RT semantic interference effect (Related vs. Unrelated) difference for cycles 2–5 with the ordinal slope effect ($r = .11$) and the repetition priming/learning effect ($r = .08$) and found no significant correlations (both *p's* > .36).

3. Experiment 2

3.1. Method

3.1.1. Subjects—Subjects were 81 native English-speaking Rice University students who received research credit or monetary compensation. All participants gave informed consent in accordance with Rice University's Institutional Review Board. Four participants were removed from further analysis either because of failures of the voice-key to register responses (n=3) or because their number of errors was outside of the group (n=1).

3.1.2. Materials and Procedure—Except where noted, all materials and procedure followed Experiment 1.

3.1.2.1. Experiment 2A: Blocked Cyclic Naming: Same as Experiment 1A.

3.1.2.2. Experiment 2B: Continuous Naming: Same as Experiment 1B.

3.1.2.3. Experiment 2C: Definition-Picture Repetition Priming: Stimuli were 25 definitions/phrases (e.g., "You rest your head on one in the bed,") taken from Wheeldon and Monsell (1994) and 50 color photographs not presented in Experiments 2A and 2B (with minimal semantic relationships between stimuli; see Appendix B for stimuli). Subjects named the 25 definitions and 50 color photographs across two naming sessions, encoding and testing. As in Experiment 1, there was no practice session. During encoding, participants named the 25 definitions. After a brief break, participants named the 50 photographs, 25 of which corresponded to the definitions from encoding phase (i.e., old items) and 25 of which were new items (i.e., new items).

3.2. Results

3.2.1 Group Analyses—We excluded RTs faster than 250 ms and outside of three SDs from each subject's mean RT. Further, RTs were removed for trials where the following occurred: omissions, microphone errors, voice key errors (coughing, sneezing, etc.), and naming errors. Errors accounted for 1.5% of the data in Experiment 2A, 16.0% of Experiment 2B, and 9.6% of Experiment 2C. We analyzed RTs following the procedures in Experiment 1. See Table 5 and Figure 4 for RT results.

3.2.1.1. Experiment 2A: Blocked Cyclic Naming: Naming latencies were significantly longer in the Related (677 ms) vs. Unrelated (650 ms) Condition (*blocking effect:* 27 ms, 95% CI [15–38])[7], replicating Experiment 1 and previous studies (e.g., Damian et al., 2001), and this difference grew across cycles (*growth effect*) (e.g., Schnur et al., 2006; see Figure 4A).[8]

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[7]As in Experiment 1A, we examined the effect at cycle 1 in Experiment 2A. There was a marginally significant facilitation effect (-6.0ms, 95% CI −11.75–0.26 ms, $t1(76) = -2.08$, $p = .04$, $t2(59) = -0.73$, $p = .47$).

[8]As in Experiment 1A, we also examined the blocked cyclic RT condition*cycle effect when excluding the first cycle (following Belke & Stielow, 2013). Both the interaction ($F1(3,228) = 4.96$, $p = .002$, $F2(3,177) = 4.02$ $p = .009$) and the linear contrast ($F1(1,76) = 8.06$, $p = .006$, $F2(1,59) = 7.38$, $p = .009$; 3.6 ms/cycle) were significant.

3.2.1.2. Experiment 2B: Continuous Naming: Naming latencies increased linearly across the five ordinal positions (*ordinal slope*), replicating previous studies (e.g., Howard et al., 2006; Navarrete et al., 2010; Runnqvist et al., 2012; Schnur, 2014). On average, subjects responded approximately 13 ms (95% CI [5.1–20.2]) slower across each ordinal position (see Figure 4B).

3.2.1.3. Experiment 2C; Definition-Picture Repetition Priming: As in Experiment 1C, only responses from the testing phase were analyzed. Two items from the testing phase were removed due to high error rates (>50%). Naming latencies were faster for old (903 ms) vs. new items (928 ms), indicative of repetition priming (average effect 25ms, 95% CI [14–37]) (this effect was significant in the by subject not by item analysis). As this task was different than the picture-picture repetition priming task used in Experiment 1C, we also calculated task reliability using the Spearman-Brown equation. The reliability of this task was −.26.

2.2.2. Correlation Analyses—Following Experiment 1, we examined correlations between the *blocking* and *growth effects* in Experiment 2A, the *ordinal slope* in Experiment 2B and the *learning effect* in Experiment 2C. Subjects displayed a wide range of performance in each of the effects (see Table 6).[9]

To test the hypothesis that semantic interference arises via the same process in blocked cyclic and continuous naming we correlated across individuals the magnitude of the *blocking* and *growth* effects in blocked cyclic naming (Exp. 2A) with the *ordinal slope* effect in continuous naming (Exp. 2B). Replicating Experiment 1, no correlation was significant (p's > .19). To test the hypothesis that learning contributes to semantic interference in blocked cyclic and continuous naming, we correlated subjects' *learning effects* (as measured by the magnitude of repetition priming, Exp. 2C) with the magnitude of their *blocking and growth effects* in blocked cyclic naming, and with their *ordinal slope* effects in continuous naming. Replicating Experiment 1, no correlation was significant (p's > .12).[10]

3.3 Discussion

In Experiment 2 we again tested the hypothesis that the blocked cyclic and continuous naming semantic interference effects and the repetition priming facilitation effect (in definition-picture priming) are manifestations of the same learning process. With data from 77 subjects, although we found significant semantic interference effects, we again found no significant correlations between the semantic interference *blocking* and *growth effects* from blocked cyclic naming and the *ordinal slope* of continuous naming. We also again did not find significant correlations between these effects and the *learning effect* as measured by definition-picture priming, keeping in mind that the *learning effect* correlation results should be tempered by the fact that the definition-picture priming task Spearman-Brown split-half reliability was low. Furthermore, to examine within a larger group of subjects (N=148)

[9]As in Experiment 1, we examined both within-task and across-task correlations for outliers using studentized deleted (jackknifed) residuals (Kleinbaum, Kupper, Nizam, & Rosenberg, 2013). Using a Bonferroni-corrected critical value to control for multiple comparisons, we removed one outlier subject from the *growth effect-ordinal slope* and the *learning effect-ordinal slope* correlations.

[10]As there is debate about the nature of cycle 1 performance in the blocked cyclic naming task (see footnotes 1 and 2), we also correlated the RT semantic interference effect (Related vs. Unrelated) difference for cycles 2–5 with the ordinal slope effect (r = .02) and the definition priming/learning effect (r = .13) and found no significant correlations (both p's > .26).

whether semantic interference effects in blocked cyclic and continuous naming were correlated, we performed analyses collapsing across Experiments 1A/B and 2A/B. We found no significant correlation between the blocked cyclic naming *blocking* or *growth effects* and the continuous naming *ordinal slope* (both r's $< .06$, p's $> .5$). As such, performance in these tasks appears to be driven by at least partially different cognitive processes.

4. General Discussion

The goal of this study was to test whether learning, a ubiquitous phenomenon across cognitive domains such as vision, memory, and language, contributes to both facilitation and interference effects in language production. To do so, we tested predictions from a computational model of naming (the Dark Side Model; Oppenheim et al., 2010) in two experiments. In each experiment, we first examined the prediction that semantic interference effects across different naming contexts arise due to the same mechanism, by testing whether the degree to which a person was slower to produce semantically related words (semantic interference) was similar across naming contexts (i.e., blocked cyclic and continuous naming). Second, we examined the prediction that the mechanism underlying semantic interference is a learning mechanism, by correlating individual learning strengths (i.e., picture-picture priming facilitation effects (Exp.1) and definition-picture priming facilitation effects (Exp. 2)) with semantic interference magnitudes. Experiments 1 and 2 replicated previous semantic interference and repetition priming effects in naming and demonstrated that the effects are robust across individuals. However, interference effects across blocked cyclic and continuous naming tasks did not correlate in either Experiment 1 or Experiment 2, nor when we doubled the number of subjects by collapsing across both Experiments. Critically, interference effects did not correlate with individual measures of the learning mechanism via picture-picture and definition-picture repetition priming. Although non-significant correlations may be due to a variety of factors, in Experiment 1 they were not due to the presence of outliers (see footnote 2), a lack of internal reliability across experimental measures (Spearman-Brown correlation $r \geq .34$ for each effect), or a limit in power to detect the correlations, as power to detect correlations of .30 or greater was .74 or greater (calculated using G*Power: Faul, Erdfelder, Lang, & Buchner, 2007). In Experiment 2, it is possible that the non-significant correlations with the measure of learning via definition-picture priming were due to the low reliability of the definition-picture priming task. However, the results from Experiment 2 are consistent with those found in Experiment 1. [11] These behavioral findings are contrary to predictions made by the Dark Side Model of naming (Oppenheim et al, 2010), suggesting that different mechanisms contribute to semantic interference in naming, where the learning which subserves facilitatory and interfering processes in naming arises from separable processes.

[11] Additionally, we calculated Bayes factor values (BF01) in JASP (2016) to estimate the strength of the evidence for the null hypothesis as compared to the alternative. Following Dienes (2014), Bayes Factor values greater than 1 suggest strong evidence for the null hypothesis and values close to 1 suggest insensitive evidence to discriminate between the null and alternative hypotheses. We found BF01 values ≥ 1.44 for correlations with the *blocking effect* (range 1.44 – 4.09, average 2.67), BF01 values ≥ 2.00 for correlations with the *growth effect* (range 2.00 – 3.91, average 2.92), BF01 values ≥ 2.00 for correlations with the *ordinal slope* (range 2.00 – 4.09, average 3.38), and BF01 values ≥ 1.44 for correlations with the *learning effect* (range 1.44 – 3.92, average 2.95). While there is always difficulty in arguing from a null result, the available evidence across both experiments is more suggestive than not that these are true null differences.

Blocked-cyclic and continuous naming tasks are used often interchangeably to draw inferences about the nature of semantic interference effects in naming and the processes that underlie speech production in general (Blocked Cyclic Naming: e.g., Belke, 2008, 2013; Damian & Als, 2005; de Zubicaray et al., 2014; Meinzer et al., 2016; Navarrete, Mahon, Lorenzoni, & Peressotti, 2016; Schnur et al., 2006, 2009; Continuous Naming: e.g., Belke, 2013; Canini et al., 2016; Howard et al., 2006; Navarrete et al., 2010; Ries et al., 2015; Rose & Abdel Rahman, 2016a, b; Schnur, 2014). While previous research has discussed the extent to which these two tasks may or may not reflect the same processes (Belke & Stielow, 2013), to our knowledge, this is the first study which provides a direct empirical comparison of semantic interference effects across these two tasks. Our results address this gap, providing empirical evidence that these tasks rely on at least partially different processes.

4.1 The nature of semantic interference in naming

Why was there no relationship between individuals' magnitude of semantic interference across two different semantically related naming contexts (blocked cyclic and continuous naming tasks)? Both tasks elicit semantic interference whereby naming multiple items from the same semantic category slows production. Interference in both tasks generally responds similarly under different conditions, for example when items are semantically or associatively similar (e.g., Abdel Rahman & Melinger, 2007; Rose & Abdel Rahman, 2016a,b; Vigliocco, Vinson, Damian, & Levelt, 2002), items are interleaved with unrelated items or time (Damian & Als, 2005; Howard et al., 2006; Schnur et al. 2006; Schnur, 2014), the stimulus modality varies (pictures vs. words; Belke, 2013; Damian et al., 2001; Navarrete et al., 2016) or when items are categorized instead of named (Belke, 2013; Damian et al., 2001). For these reasons, blocked cyclic and continuous naming are considered variations of the same paradigm (i.e., serial naming) and multiple researchers when discussing semantic interference effects in speech production attribute these effects to the basic process of learning independent of the task in which they are observed (e.g., blocked cyclic naming or continuous naming; Belke & Stielow, 2013; Breining, Nozari, & Rapp, 2016; Crowther & Martin, 2014; Damian & Als, 2005; Howard et al., 2006; Kleinman, Runnqvist, & Ferreira, 2015; Llorens, Dubarry, Trebuchon, Chauvel, Alario & Liegeois-Chauvel, 2016; Navarrete et al., 2016; Navarrete et al., 2014; Oppenheim et al. 2010; Rose & Abdel-Rahman, 2016a,b; Schnur et al. 2006).

One possibility for the lack of relationship between individuals' magnitude of semantic interference across the two naming contexts is that the interference across tasks occurs at different levels in the language system (e.g., semantic, semantic to lexical, and lexical). However, the evidence for differential loci is mixed. For example, categorizing pictures as living/non-living, a task which does not require lexicalization, creates facilitation in continuous naming (Belke, 2013; Riley et al., 2015) and blocked-cyclic naming (Belke, 2013), but contrasting null effects have been also observed in blocked-cyclic naming (Riley et al., 2015; Damian et al. 2001). Naming pictures that are associatively related creates interference in blocked-cyclic naming (Abdel Rahman & Melinger, 2007) and in continuous naming (Rose & Abdel Rahman, 2016a), but de Zubicaray et al. (2014) found null effects for blocked-cyclic naming. Reading written words with gender-marked determiners instead of naming pictures (a task designed to tap the lexical level) sometimes creates semantic interference (Damian et al., 2001; Navarrete et al. 2010) or eliminates it in blocked cyclic naming (Belke, 2013) and continuous naming (Belke, 2013; Navarrete et al., 2010). The exact locus of interference in these tasks continues to be debated (cf. Belke 2013, Janssen, Carreiras, & Barber, 2011; Riley et al., 2015; Rose & Abdel Rahman 2016a). Given the mixed evidence to date, the possibility that these effects occur at different levels in the production system is currently an unlikely explanation for the lack of correlation between them.

Another possibility to explain the lack of correlation between tasks is that the repeating nature of blocked-cyclic naming introduces different mechanisms and/or strategies in comparison to continuous naming. For example, repeating small sets of items in blocked cyclic naming may allow participants to hold items in short-term memory (see Crowther & Martin, 2014) and recruit executive top-down strategies that cause interference to differ from continuous naming (Abdel Rahman & Melinger, 2011; Belke, 2008; Belke & Stielow, 2013). Previous research provides support for a difference in the task demands between blocked cyclic and continuous naming, suggesting that the former recruits executive processes and the latter does not. Specifically, Belke (2008) used the blocked cyclic naming task with and without a concurrent digit-retention task that relies on working memory resources and found that a working memory load (digit string) increased the magnitude of semantic interference. This finding indicates that taxing working memory resources holds captive executive processes that subjects would otherwise use to attenuate the semantic interference effect, thus leading to increased semantic interference. Also, Damian and Als (2005) found that interleaving fillers between critical trials increased the semantic interference effect (20 vs. 29 ms), further supporting the idea that without the ability to use executive processes to encode the repeating set and hold it in working memory, subjects were unable to attenuate semantic interference. While these processes may be at play in blocked cyclic naming, recent findings reveal no such role for executive strategic processes in continuous naming performance. Following Belke (2008), Belke and Stielow (2013) used the same digit-retention task in the continuous naming paradigm. Contrary to Belke (2008), working memory load did not change the magnitude of the semantic interference effect in continuous naming (Belke & Stielow, 2013). Thus, a possible explanation for why semantic interference effects did not correlate between blocked cyclic and continuous naming is that by virtue of repeating items, the blocked cyclic naming task promotes the recruitment of executive top-down strategies while continuous naming does not, although see Llorens, Trebuchon, Ries, Liegeois-Chauvel, & Alario (2014). In sum, our results demonstrate that the semantic interference in naming elicited in blocked cyclic and continuous naming is different, but the results do not address the source of this difference. Future research should explore how the mechanism(s) subserving semantic interference allows interference to change depending on the implicit (e.g., Goschke & Bolte, 2007; Schnur 2014) and/or explicit processing (e.g., Abdel Rahman & Melinger, 2011; Belke, 2008) inherent in the particular naming context.

4.2 Learning Mechanism

That the learning mechanism as measured by picture-picture repetition priming (and also as measured by definition-picture repetition priming) did not correlate with the magnitude of semantic interference across individuals is either due to differences between these paradigms (as previously described), and/or that contrary to Oppenheim et al.'s (2010) model, repetition priming does not reflect the learning that creates semantic interference (see also Navarrete et al. 2012). The learning mechanism implemented in Oppenheim et al.'s model reflects processes responsible for both repetition priming and semantic interference effects through persistent lexical-semantic connection weight changes. Oppenheim et al. (2010) state that these effects are "…two sides of the same coin…" (p. 227), both served by a unitary learning mechanism in which a single parameter (the learning rate) determines both the weakening and strengthening functions of the learning process. Yet learning mechanism strength (measured by repetition priming) did not correlate with semantic interference effects in blocked cyclic or continuous naming.

Because blocked cyclic naming involves additional processes outside of the language production system (e.g., executive processes; Belke, 2008) this may explain why semantic interference in this task did not correlate with the learning measure. However, semantic interference in the continuous naming paradigm should show a relationship with measures of learning since this task does not necessarily involve mechanisms external to the language system (Belke & Stielow, 2013; cf. Schnur, 2014), a relationship we did not observe. Although Oppenheim et al. (2010) propose that repetition priming reflects the same learning mechanism that operates to create semantic interference in naming the results here suggest that this is not the case.

While similar characteristics between repetition priming and semantic interference effects (e.g., long-lasting, cumulative, e.g., Howard et al., 2006; Oppenheim et al., 2010; cf. Belke & Stielow, 2013; Schnur, 2014) suggest that they are the result of the same process (i.e., learning; Damian & Als, 2005; Wheeldon & Monsell; 1994), these two effects may occur at different levels of the cognitive system. With regards to picture-picture repetition priming which measures priming at multiple levels in the system (e.g., visual processing, conceptualizing, lexical access, etc.), one possibility is that the repetition priming effect found in this task is best attributed to processes outside of naming, and as such a picture-picture repetition priming task would not be predicted to correlate with the semantic interference naming tasks. However, there is evidence to suggest this is not the case. While some have suggested that picture-picture repetition priming effects are the result of language external processes such as visual and conceptual processing (i.e., object recognition, Tulving & Schacter, 1990), behavioral and neuroimaging evidence suggests that picture-picture repetition priming effects occur both during object recognition processes and during the process of word production (i.e. lexical selection, phonological selection, and articulation, e.g., Barry, Hirsh, Johnston, & Williams, 2000; Ellis, Flude, Young, & Burton, 1996; Francis et al., 2008; van Turennout et al., 2000). In a review of the repetition priming literature, Francis (2014) explores the contribution of object recognition and word production processes to priming effects in picture naming. Priming effects are found at the object recognition level, for example when the same object is used but the prime and test responses are different (e.g., naming in two different languages; e.g., Hernandez & Reyes, 2002). However, as seen in Experiment 2 and elsewhere, priming effects are also found at the word production level, for example when the prime and test responses are the same but the task materials differ in modality (i.e., the repetition priming task adopted in Experiment 2: naming to definition and then naming a picture; cf., Francis et al., 2008). Additionally, because there is no priming between homophones, repetition priming is not isolated to articulation alone (Wheeldon & Monsell, 1992). Overall, the evidence suggests that word production processes play a critical role in repetition priming effects.

Although repetition priming effects are not isolated to processes outside of the language system, differences in the nature of repetition priming and semantic interference effects indicate that they may occur at different levels of the language system, potentially explaining the lack of relationship between the learning measures and the semantic interference effects seen here. For example, the direction of the effects is inherently different, where repetition priming reflects improvement in naming (faster RTs and fewer errors), while semantic interference reflects decrements in naming (slower RTs and more errors). Both semantic interference (e.g., Damian & Als, 2005; Howard et al., 2006; Schnur et al., 2006) and repetition priming (e.g., Durso & Johnson, 1979; Cave, 1997) are temporally persistent, supporting the idea that learning occurs in each task, causing changes to the language system which impact future production. However, the time course of semantic interference differs from repetition priming, as semantic interference occurs with up to eight items between category members, but dissipates when many more unrelated pictures are named between related items (Schnur, 2014; Wheeldon & Monsell, 1994). Repetition priming not only lasts with up to 50 intervening items between repetitions (Durso & Johnson, 1979) but also with up to 48 weeks between repetitions (Cave, 1997). Furthermore, although Oppenheim et al. (2010) modeled both repetition priming and semantic interference at the same level (lexical-semantic links), others suggest that repetition priming results from incremental learning that strengthens connections between lexical and phonological levels (lexical-phonological links) (e.g., Wheeldon & Monsell, 1994; Damian & Als, 2005). Francis (2014) summarizes the current state of affairs:

> It remains unknown what proportion of the priming of the word production processes of picture naming is due to speeded access to the lemma (i.e., the syntactic word form) from the concept, and how much is due to speeded access to the phonological word form from the lemma. (p. 1303).

Given the differences in direction and longevity of the effects, these two effects may indeed be occurring at different levels or by different processes. When Damian and Als (2005) proposed that semantic interference effects result from learning processes similar to those in repetition priming (see also Vitkovich & Humphreys, 1991), they advised that “this solution has the benefit that the same principle…proposed to account for repetition priming…can account for semantic context effects as well, just at a different locus” (p. 1382). Our results are consistent with this interpretation, and a test of this account is found in differential predictions for patients with brain damage. Specifically, if the learning subserving repetition priming is different from that subserving semantic interference, then we predict a double dissociation between patients with brain damage where patients will exhibit impaired facilitation (i.e., damaged strengthening as seen by no benefit of repetition priming) but intact interference (i.e., weakening as seen by normal or excessive semantic interference effects) and vice versa. Overall, while learning processes are important factors in speech production, the results from this study suggest that repetition priming and semantic interference do not involve the same learning process and/or locus.

5. Conclusion

In this study we tested whether interference and facilitation in naming are related across different naming contexts to examine whether the same learning principle governs the changes in language processing that result from experience. We tested predictions of the computational Dark Side Model (Oppenheim et al., 2010) to determine whether semantic interference effects in two different naming contexts (i.e., blocked cyclic and continuous naming) arise from the same mechanism, specifically a learning mechanism. Using four picture naming tasks across two experiments, we examined individual differences in susceptibility to semantic interference and repetition priming facilitation, the latter of which is a potential measure of the strength of the learning mechanism. Together, these results demonstrate that semantic interference across naming contexts arises from, or is affected by different sources, and the learning mechanism as described in the Dark Side Model does not subserve semantic interference. Future research should further explore how learning occurs in naming. Learning may differ in its ability to strengthen and weaken connections, and the changes learning engenders may be vulnerable to decay at different rates, depending on the domain and task. Furthermore, models of language production should incorporate the role that executive processes play in modulating the effects of learning. That the learning behind interference differs from the learning underlying facilitation may explain how incremental changes to the language system do not eventually lead to the inability to speak fluently. Overall, these differences may extend beyond the domain of language, providing insight as to how learning causes dynamic changes to many cognitive processes.

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Appendix A

Experiment 1 Stimuli

Acceptable alternatives are listed in parentheses.

Experiment 1A

Fruit: apple, grapes, banana, orange, pear

Tools: paintbrush, pliers, saw, screwdriver, level

Zoo Animals: elephant, giraffe, hippo, lion, zebra

Farm Animals: pig, goat, rabbit (bunny), sheep, horse

Insects: ant, bee, ladybug, dragonfly, spider

Vegetables: broccoli, carrot, tomato, celery, potato

Accessories: earrings, watch, sunglasses, necklace, tie

School Supplies: chalk, envelope, stapler, eraser, pencil

Musical Instruments: violin, tambourine, piano, guitar, trumpet

Kitchen Items: rolling pin, cup, spoon, plate, toaster

Electronics: battery, CD, keyboard, calculator, printer

Furniture: bed, chair, desk, table, stool

Experiment 1B

Birds: duck, eagle, owl, parrot, swan (goose)

Transportation: bus (schoolbus), car, helicopter, plane (airplane), van

Body Parts: ear, eye, foot, hand, nose

Appliances: dishwasher, fridge (refrigerator), microwave, oven, dryer

Buildings: castle, church, lighthouse, windmill, barn

Fish: eel, shark, stingray, swordfish, goldfish

Headgear: beret, sombrero, crown, cap (hat), hardhat (helmet)

Clothing: bra, jacket (coat), pajamas, skirt, sock

Reptiles and Amphibians: crocodile (alligator), frog (toad), lizard, snake, turtle

Landscape Features: beach, field, mountain, waterfall, desert

House Parts: chimney, door, fireplace, roof, window

Celestial Phenomena: clouds, comet (meteor), lightning, moon, rainbow

Experiment 1C

New Items: binder, bow (ribbon), bowl, brain, cane, cooler, cracker, daffodil (flower), drill, elbow, headphones, kayak (canoe), knife, ladder, lamp, monitor (TV), perfume (cologne), pitcher, plant, radio, rattle, razor, shirt (jacket, coat), snail, starfish, thimble, tripod, whisk (mixer)

Old Items: bandage (gauze), accordion, box, bracelet, butterfly, cigarette, comb, corkscrew, cow, drum, fan, gum, gun, house, jar, mirror, overalls, pasta (noodles), pen, pizza, rug, soap, speaker, syringe (needle), tape, telephone (phone), thread (string), tractor, vacuum, wheel

Appendix B

Experiment 2C Stimuli

Primes (Definitions taken from Wheeldon & Monsell, 1994)

Definition	Response
You sweep the floor with a ____	broom
Used in observatories to gaze at the planets	telescope
You rest your head on one in bed	pillow
piece of plastic with teeth for tidying the hair	comb
Known as man's best fiend	dog
It erupts violently spewing out lava and hot gas	volcano
A child often sucks its ____	thumb
You fly it on the end of a string on windy days	kite
Worn around the waist to hold up trousers	belt
Cinderella had a ____ Godmother	fairy
Piece of fine net covering a bride's face	veil
The waiter poured her another ____ of wine	glass
He carried his packed lunch in a brown paper ____	bag
The largest creature that swims in the sea	whale
A decorative container for flowers	Vase
It has pipes and provides the music in church	Organ
You strike one to make a flame	Match
Warm covering you wear on your hand	Glove
A man who lives in a monastery	monk
In the race the tortoise beat the ____	hare
It falls in white fluffy flakes from the sky	snow
She put the book on the top ____	shelf
You roll them in games of chance	dice
A piece of bread browned on both sides	toast
A wooden seat hung from ropes you push to and fro	swing

Pictures

Bag, bell, belt, bottle, broom, bullet, castle, cheese, chicken, coat, comb, curtains, dice, dog, fairy, fork, gate, glass, glove, gun, holly, kettle, kite, lamp, leopard, map, match, organ, pie, pillow, pipe, priest, rabbit, shelf, shoe, sink, snow, stone, sun, swing, telescope, thumb, toast, television, tire, vase, veil, volcano, wallet, whale

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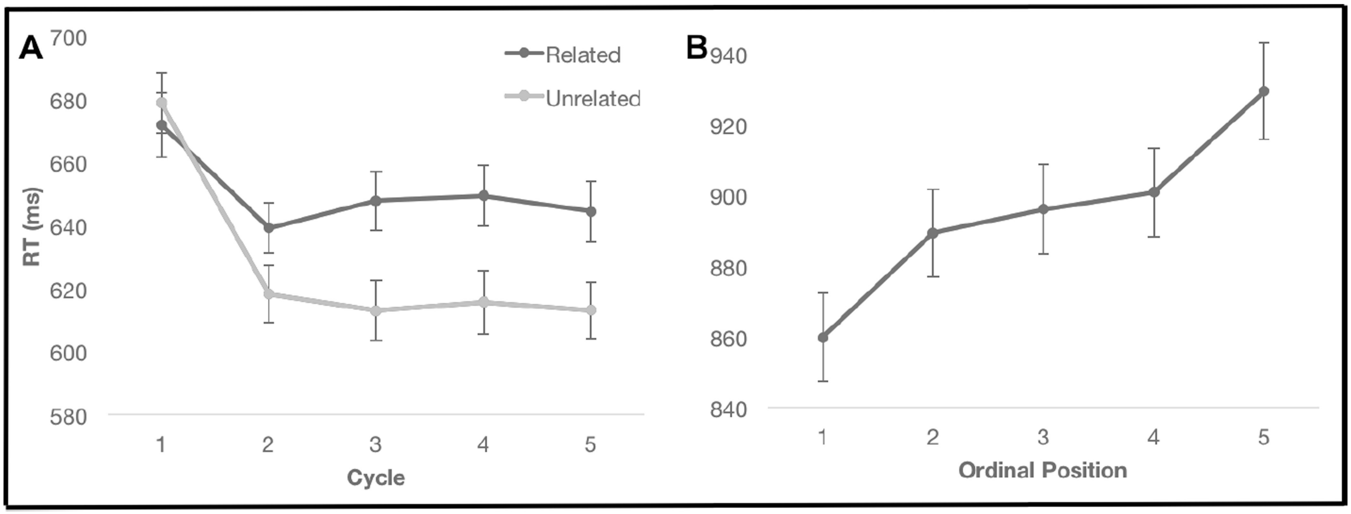

Figure 1.

Experiments 1A and 1B Results. Experiment 1A mean RTs (ms) by condition (Related, Unrelated) and presentation cycle (1–5) (panel A). Experiment 1B mean RTs (ms) by ordinal position (panel B). Error bars represent within-subject 95% confidence intervals.

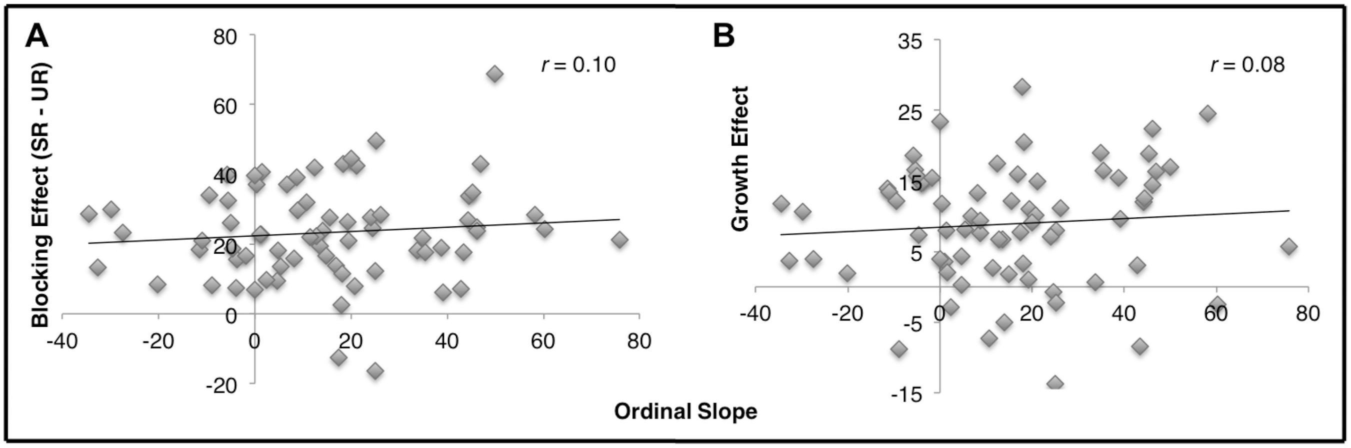

Figure 2.

Scatterplots of subjects' RT (ms) continuous naming *ordinal slope* effects with blocked cyclic *blocking* (A) and *growth* effects (B) (SR, semantically related; UR, unrelated).

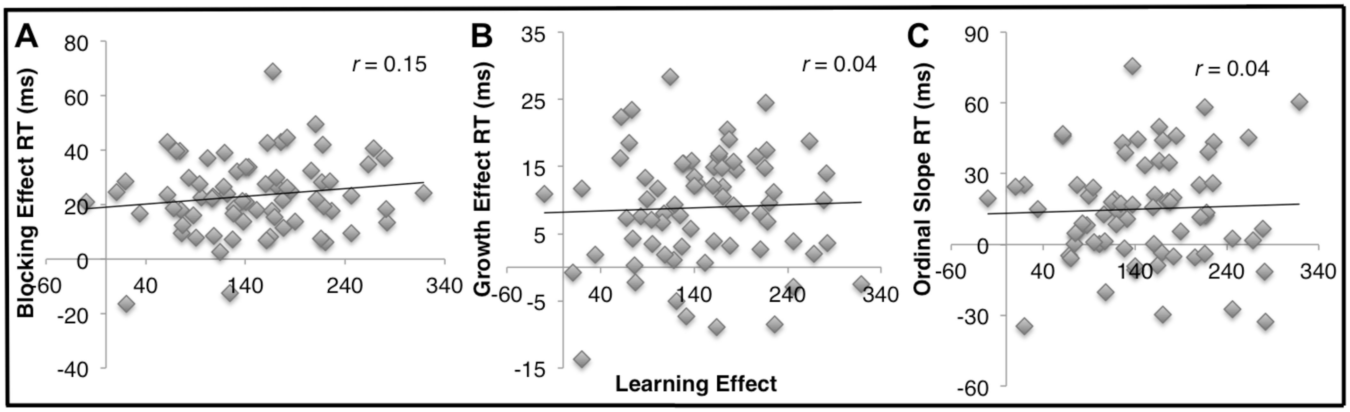

Figure 3.
Scatterplots of learning mechanism strength plotted by semantic interference effect magnitudes. We correlated the strength of individual learning mechanism as assessed by the magnitude of repetition priming with individual blocked cyclic naming *blocking effects* (A), blocked cyclic naming *growth effects* (B), and continuous naming *ordinal slopes* (C).

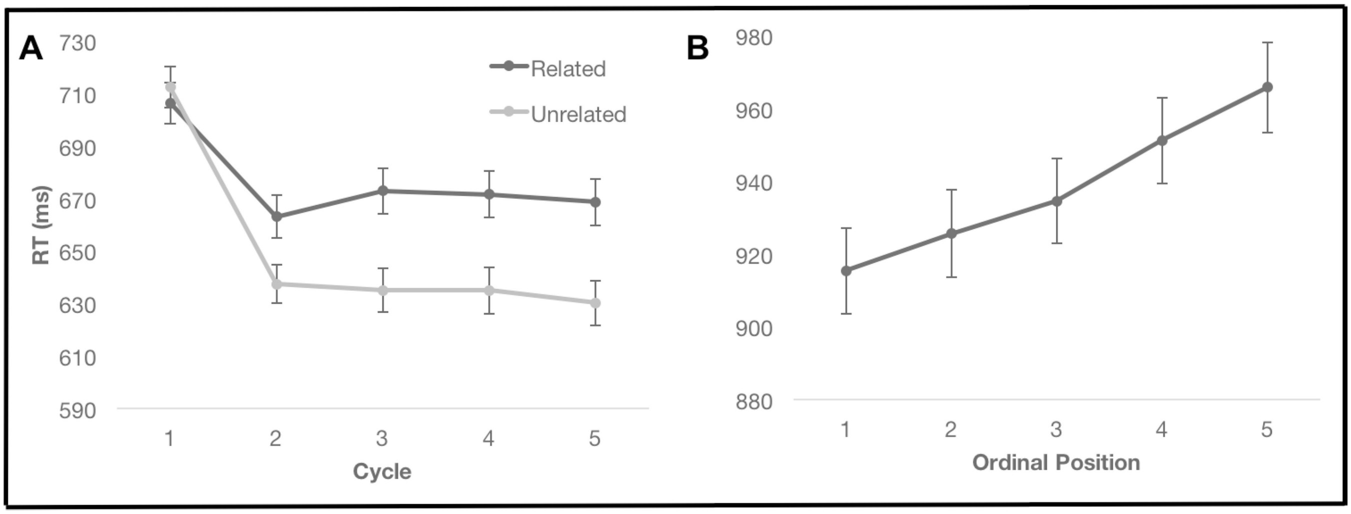

Figure 4.

Experiments 2A and 2B Results. Experiment 2A mean RTs (ms) by condition (Related, Unrelated) and presentation cycle (1–5) (panel A). Experiment 2B mean RTs (ms) by ordinal position (panel B). Error bars represent within-subject 95% confidence intervals.

Table 1

Experiment 1 ANOVA results by subject (F_1/t_1) and by item (F_2/t_2) (1A, 1C) or category (F_2) (1B) (cf., Howard et al., 2006). All effects significant at $p < .001$.

Experiment	ANOVA			
Effect	***df***	***F_1/t_1***	***df***	***F_2/t_2***
1A: Blocked Cyclic Naming				
Blocking	(1,70)	195.76	(1,59)	70.73
Cycle	(4,280)	100.92	(4,236)	100.61
Growth (Blocking * Cycle Linear Contrast)	(1,70)	80.34	(1,59)	34.33
1B: Continuous Naming				
Ordinal Slope (Linear Contrast)	(1,70)	31.29	(1,11)	36.43
1C: Repetition Priming				
Condition (Old vs. New)	(70)	17.54	(56)	7.55

Note: ANOVA = analysis of variance

Table 2

Calculations for individual interference and facilitation effects from blocked cyclic naming (Exps. 1A/2A, blocking, growth), continuous naming (Exps. 1B/2B, ordinal slope), and repetition priming (Exps. 1C/2C, learning).

Effects	Calculation
Blocking Effect	Related – Unrelated (ms)
Growth Effect	Slope of blocking effect across five cycles (ms)
Ordinal Slope	Slope across five ordinal positions (ms)
Learning Effect	New Items – Old Items (ms)

Table 3

Spearman-Brown reliability correlations for blocked cyclic naming (Exp. 1A: blocking and growth effects), continuous naming (Exp. 1B: ordinal slope) and repetition priming (Exp. 1C: learning effect).

Effect	Spearman-Brown Correlation
Blocking Effect	.34
Growth Effect	.44
Ordinal Slope	.40
Learning Effect	.44

Table 4

Descriptive statistics for the individual interference and facilitation effects from blocked cyclic naming (Exp. 1A, blocking, growth), continuous naming (Exp. 1B, ordinal slope) and repetition priming (Exp. 1C, learning). Note: M: Mean, SD: Standard Deviation, Min: Minimum, Max: Maximum.

Effects	M	Median	SD	Min	Max
Blocking Effect	23.28	22.70	13.78	−16.35	68.81
Growth Effect	8.90	9.59	8.36	−13.69	28.36
Ordinal Slope	15.05	14.01	22.67	−34.51	75.78
Learning Effect	149.01	143.41	71.56	−19.81	318.52

Table 5

ANOVA results by subject (F_1/t_1) and by item (F_2/t_2) (2A, 2C) or category (F_2) (2B) (cf., Howard et al., 2006). All effects significant at p < .001 except for the repetition priming by item (t2) effect (p = .35).

Experiment	**ANOVA**			
Effect	***df***	***F_1/t_1***	***df***	***F_2/t_2***
2A: Blocked Cyclic Naming				
Blocking	(1,76)	230.33	(1,59)	55.06
Cycle	(4,304)	160.01	(4,236)	128.39
Growth (Blocking * Cycle Linear Contrast)	(1,76)	102.67	(1,59)	39.30
2B: Continuous Naming				
Ordinal Slope (Linear Contrast)	(1,76)	22.42	(1,11)	22.13
2C: Repetition Priming				
Condition (Old vs. New)	(76)	4.33	(46)	0.95

Note: ANOVA = analysis of variance

Table 6

Descriptive statistics for the individual interference and facilitation effects from blocked cyclic naming (Exp. 2A, blocking, growth), continuous naming (Exp. 2B, ordinal slope) and repetition priming (Exp. 2C, learning). Note: M: Mean, SD: Standard Deviation, Min: Minimum, Max: Maximum.

Effects	M	Median	SD	Min	Max
Blocking Effect	26.87	26.13	15.20	−1.23	67.09
Growth Effect	10.00	8.73	8.66	−11.29	41.26
Ordinal Slope	12.64	12.65	23.42	−70.03	66.51
Learning Effect	25.47	25.66	51.65	−109.38	141.49