Cogn Affect Behav Neurosci (2011) 11:32–43
DOI 10.3758/s13415-010-0009-7

Effects of near and distant semantic neighbors on word production

Daniel Mirman

Published online: 18 November 2010

Abstract One way to examine the dynamics of word processing is to investigate how processing is affected by the co-activation of similar words ("neighbors"). A unique prediction of attractor dynamical models is that near neighbors should exert inhibitory effects and distant neighbors should exert facilitative effects. In study 1, data from 62 unselected chronic aphasia patients revealed a higher rate of semantic errors for words with many near semantic neighbors and fewer semantic errors for words with many distant semantic neighbors. In study 2, this basic result was replicated in controls using a speeded picture-naming paradigm. Together, these two studies provide strong new evidence consistent with the attractor dynamics view of neighborhood effects. In addition, analyses of correlations between effect sizes and lesion locations, and comparisons with the existing literature on semantic deficits in aphasia and the speeded picture-naming paradigm, all provide converging evidence that the semantic error patterns found in the present studies were due to disruptions of cognitive control mechanisms.

Keywords Attractor dynamics · Semantic processing · Cognitive control · Neighborhood density · Aphasia · Picture naming

All theories of word processing agree that multiple similar candidate words are activated during processing. Words can be similar in terms of their spelling (orthography), sound (phonology), or meaning (semantics). One way to examine the dynamics of word processing is to investigate how processing is affected by the number or degree of similarity of these co-activated words, also called "neighborhood size" or "neighborhood density". Theoretical interpretations of neighborhood effects have generally proposed either facilitation due to collaborative gang effects of many active words (e.g., McClelland & Rumelhart, 1981) or inhibition due to competition between many active words (e.g., Luce & Pisoni, 1998). In a recent study of visual word recognition, Mirman and Magnuson (2008) found opposite effects of near and distant semantic neighbors: words with many near neighbors (highly similar concepts) were recognized more slowly than words with few near neighbors, and words with many distant neighbors (somewhat similar concepts) were recognized more quickly than words with few distant neighbors.

Mirman and Magnuson (2008) noted that such opposite effects of near and distant neighbors are not consistent with specified inhibitory or facilitative effects of neighbors. Rather, they argued that these effects are indicative of emergent effects of nonlinear attractor dynamics (see Spivey, 2007, for an accessible introduction to attractor dynamics in cognition). In attractor models of semantic cognition (e.g., Cree, McRae, & McNorgan, 1999; O'Connor, Cree, & McRae, 2009; Rogers et al., 2004) attractors are stable states that correspond to a unique concept's combination of features. Given a model state defined by a pattern of activation over the full set of semantic features, the model tends to gravitate toward the nearest stable state or states. The closer the model gets to an attractor, the more strongly it is pulled towards that stable state. Because near semantic neighbors are, by definition, close to the target attractor, the model must pass near them and be slowed in its approach toward the target by the pull of the neighbor attractor. In contrast, distant neighbors are, by definition, farther from the target, so they do not create this high degree of competition.

D. Mirman (✉)
Moss Rehabilitation Research Institute,
50 Township Line Rd. Elkins Park,
Philadelphia, PA 19027, USA
e-mail: mirmand@einstein.edu

However, distant neighbors are far more numerous than near neighbors (i.e., in general, a concept will have many more neighbors that share a few features than neighbors that share many features), so when the model is in an initial, neutral state, the combination of small pulling effects from many distant neighbors all pulling toward the general vicinity of the target facilitates the initial movement toward the target attractor. One way to visualize attractor spaces is in terms of three-dimensional manifolds where the effects of attractors are represented as vertical gradients, such that local minima represent stable states and slopes represent strength of the pull in a particular direction. Figure 1 shows such schematic attractor landscapes that demonstrate the different topological consequences of having many or few near and distant neighbors. Mirman and Magnuson analyzed simulations of an attractor dynamics model of semantic processing (O'Connor et al. 2009) and found that it exhibited detrimental effects of near neighbors and facilitative effects of distant neighbors,

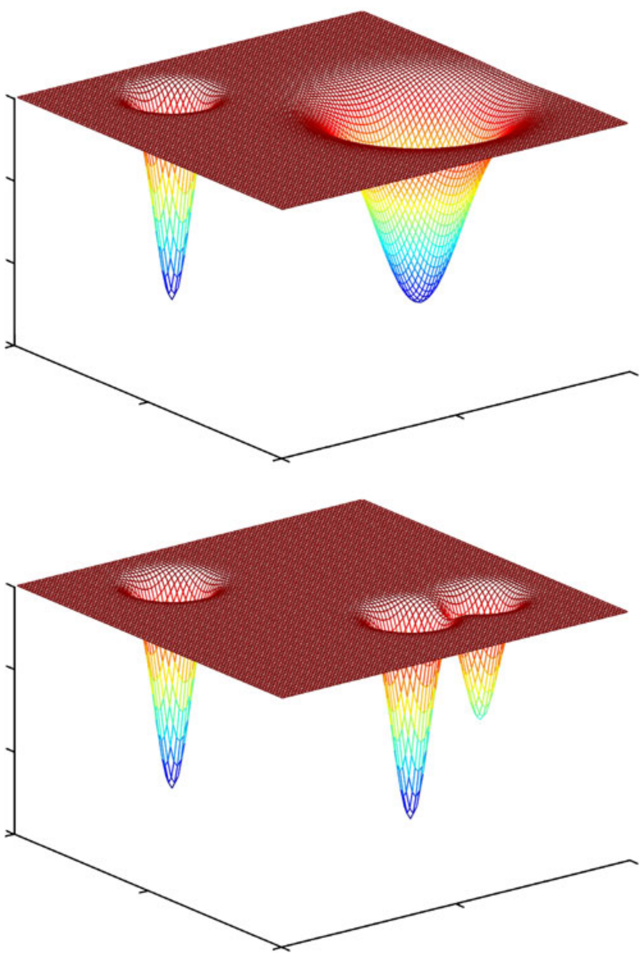


Fig. 1 *Top*: Schematic diagram of narrow and broad attractor basins resulting from few and many distant neighbors, respectively. *Bottom*: Schematic diagram of a single attractor basin and an attractor with a subbasin formed by a near neighbor

consistent with this attractor dynamics account of near and distant neighbor effects.

The attractor dynamics account is appealing because it provides an integrated account for both the facilitative effects of distant neighbors and the detrimental effects of near neighbors. This account is a general theoretical framework for cognition (e.g., Spivey, 2007) and not specific to semantic effects on visual word recognition. As a result, it predicts analogous opposite effects of near and distant neighbors in other domains and tasks. Consistent with this prediction, word recognition studies have found related effects for phonological neighbors (opposite effects of phonotactic probability and one-phoneme-different neighbors: Luce & Large, 2001) and orthographic neighbors (opposite effects of one-letter-different neighbors and transposed-letter neighbors: Andrews, 1996). In contrast, this prediction has never been tested in word production. If attractor dynamics is the right theoretical framework for semantic processing (and perhaps cognitive processing in general), then opposite effects of near and distant semantic neighbors should be found in word production as well as word recognition.

In the word recognition study (Mirman & Magnuson, 2008) participants performed a concreteness judgment task (all of the target concepts were concrete and there were abstract filler concepts), thus the semantic neighbor effects could be reasonably assumed to arise from semantic processing, because there was unlikely to be substantial neighbor interactions at the output (a concrete concept's neighbors are generally also concrete). In contrast, in picture naming, semantic processing is a relatively early stage, with lexicalization and articulation processes building on core semantic processing. As a result, difficulty in semantic processing can lead to naming errors due to breakdowns at multiple levels of processing. In other words, given slower settling for concepts with few distant neighbors or many near neighbors, picture naming errors could arise due to (a) disruptions of the attractor landscape (impairment of core semantic knowledge), (b) disruptions of how settling into a semantic concept attractor maps to a specific word (impairment at the semantic-lexical interface), or (c) domain-general disruptions in the dynamics of cognitive processing that affect all processes (impairment of cognitive control). In sum, semantic neighborhood effects on errors in picture naming could be due to impairments of core semantic knowledge, impairments of domain-specific response selection (i.e., semantic-lexical interface), or impairments of domain-general response selection (i.e., cognitive control). These alternatives will be revisited in greater detail in the General Discussion section.

The present studies tested the predicted opposite effects of near and distant semantic neighbors by examining the patterns of errors produced by aphasic patients (study 1) and speeded controls (study 2) in picture naming. Recent studies (Blanken, Dittman, & Wallesch, 2002; Bormann, Kulke, Wallesch, & Blanken, 2008) found that number of semantic neighbors did not affect overall error rate in aphasic picture naming, but that the distribution of error types was shifted: there were more semantic errors and fewer omission errors for concepts with many semantic neighbors. Those studies considered semantic neighbors defined by having independent raters estimate the number of members in the target's semantic category, so they did not distinguish between near and distant semantic relations. Similarly, studies of patients with semantic impairments (Lambon Ralph, Lowe, & Rogers, 2007; Rogers et al., 2004) and of speeded controls (Hodgson & Lambon Ralph, 2008) have argued that tighter clustering of living things accounts for higher error rates in naming living things compared to artifacts. Like the studies of aphasic picture naming, these studies did not examine whether near and distant semantic neighbors may exert opposite effects on word production. In contrast, the present studies specifically tested whether near and distant semantic neighbors exert opposite effects on word production. The two studies provide converging evidence demonstrating facilitative effects of distant semantic neighbors and detrimental effects of near semantic neighbors on picture naming and provide further evidence consistent with the attractor dynamics view of neighbor effects in language processing. The results also suggest that these effects reflect interactions between domain-specific semantic processes and domain-general control processes.

Predictions

The general predictions were that there would be fewer errors for concepts with many distant neighbors and more errors for concepts with many near neighbors. Since these are semantic neighbors, their effects should be reflected specifically in the proportions of semantic errors—incorrect naming responses that are semantically related to the target word. For aphasic patients, overall error rates are likely to primarily reflect severity of impairment rather than the effects of semantic neighbors because aphasic patients may have impairments at different levels of processing and produce varied distributions of error types (e.g., Schwartz, Dell, Martin, Gahl, & Sobel 2006). In contrast, previous studies suggest that semantic errors are the dominant error type for controls (Dell, Schwartz, Martin, Saffran, & Gagnon, 1997), so speeded controls may show semantic neighbor effects on overall error rates as well as the rates of semantic errors. Indeed, because the rates of a given error type (even the dominant type) are likely to be quite low for controls, differences in overall error rates may reflect semantic neighbor effects most clearly.

There was no prediction regarding a possible statistical interaction between the effects of near and distant neighbors because many other factors could influence whether the combination of facilitative and detrimental factors would be additive, over-additive, or under-additive. For example, for a low difficulty task with a nonlinear relationship between task difficulty and error likelihood, a small increase in difficulty (many near neighbors or few distant neighbors) might have a negligible effect on error rates, but a larger increase (many near neighbors and few distant neighbors) might have an over-additively large effect on error rates. The opposite pattern could emerge if baseline difficulty is moderately high.

In sum, patients and speeded controls were predicted to make more semantic errors for concepts with many near neighbors and fewer semantic errors for concepts with many distant neighbors. Speeded controls were also predicted to show the same effects for overall error rates and there was no specific prediction regarding whether there would be a particularly high error rate for concepts with many near and few distant semantic neighbors.

Study 1: Aphasic patients

Study 1 investigated the effects of near and distant semantic neighbors on picture naming in aphasic patients. The picture naming data were drawn from the Moss Aphasia Psycholinguistics Project Database (Mirman, Strauss et al. under review; available at www.mappd.org) of patient performance on the 175-item Philadelphia Naming Test (Dell et al., 1997; Roach, Schwartz, Martin, Grewal, & Brecher, 1996). The stimulus pictures were black-and-white line drawings of non-unique entities from varied semantic categories (tools, non-manipulable objects, animals, plants, and other natural kinds). The pictures had high familiarity, name agreement, and image quality. Each picture was presented individually for naming and the first complete (non-fragment) response was scored. In this study, the focus was on overall errors, semantic errors (synonyms, category coordinates, superordinates, subordinates, or strong associates of the target), and form errors (words that are phonologically similar to the target word). Other errors included mixed errors (words that are semantically and phonologically similar to the target word), nonword errors, descriptions, unrelated responses, and omissions (failure to respond). The full set of PNT materials, test administration procedures, and detailed description of the scoring procedure is available at http://www.ncrrn.org/assessment/pnt. For the patients and items considered in these experiments, the overall error rate was 31.5%, with 3.7% semantic errors, 3.8% form errors, 8.2% nonword errors, and 15.8% other errors.

Methods

Materials As in the original study of near and distant semantic neighbor effects (Mirman & Magnuson, 2008), near and distant neighbors were defined based on cosine distance between semantic feature vectors derived from a large feature norm corpus (McRae, Cree, Seidenberg, & McNorgan, 2005). This feature norm corpus contains 541 concepts covering a broad range of living and nonliving concepts used in studies of semantic memory. Thirty participants from McGill University and/or the University of Western Ontario produced up to ten features for each concept, resulting in a total of 2,526 unique features.

As noted above, the picture naming data were drawn from the Moss Aphasia Psycholinguistics Project Database of patient performance on the Philadelphia Naming Test (PNT). Ninety-five of the PNT words were in the feature norms; these words were divided into four sets (2 x 2 factorial design) that independently manipulated near and distant neighborhoods (few vs. many neighbors of each type) and were matched on other variables known to affect word processing. Near and distant neighbors were defined based on cosine similarity between feature vectors, as in Mirman and Magnuson (2008), with near neighbors defined as having cosine greater than 0.4 and distant neighbors defined as having cosine greater than 0.0 and less than 0.25. The attractor dynamics account predicts that the effect of neighbors will depend on their impact on the attractor landscape, so the distinction between "near" and "distant" neighbors is merely a convenient operationalization of this prediction and not specific to these particular thresholds used for selecting the materials. These thresholds were chosen because they were consistent with the thresholds used by Mirman and Magnuson in their study of word recognition and, as in that study, were chosen to create a relatively large semantic similarity difference between near and distant neighbors while allowing large enough item sets to match the conditions on other variables.

The four conditions were matched on number of semantic features (Pexman, Holyk, & Monfils, 2003); word frequency (based on HAL norms and the American National Corpus; Lund & Burgess, 1996; Ide & Suderman, 2004); word length in syllables, phonemes, and letters; orthographic neighborhood (number of orthographic neighbors and cumulative bigram frequency); and phonological neighborhood (number of phonological neighbors and cumulative phoneme transition probability). None of the control variables was reliably different between conditions (all $p > 0.25$). Due to limitations of the PNT and McRae et al. (2005) item corpora, it was not possible to match the conditions on number of living vs. nonliving things. However, for the 95 words and 62 patients considered here, there were no statistically reliable differences in accuracy or rate of semantic errors between living and nonliving things (Living things: 69.1% correct, 3.3% semantic errors; Nonliving things: 67.7% correct, 4.0% semantic errors; both $p > 0.3$). The mean stimulus properties by condition are shown in Table 1 and the full stimulus list is provided in the Appendix.

Participants Picture naming responses were collected from 62 patients[1] with clinically diverse chronic aphasia as a result of a left-hemisphere cerebrovascular accident. The patients had no major psychiatric or neurologic co-morbidities, were pre-morbidly right handed, had English as the primary language, adequate vision and hearing without or with correction, and some ability to name pictures. CT or MRI confirmed left hemisphere cortical lesion. The patients had a mean age of 58 (*range* = 26–78), mean years of education of 14 (*range* = 10–21), and a wide range of performance on picture naming (PNT: 2–97% correct, 0–12% semantic errors), verbal comprehension (synonym judgment (Martin, Schwartz, & Kohen, 2006): 33–100% correct), and nonverbal semantics (Camels and Cactus (Bozeat et al., 2000): 36–95% correct). For more detailed patient information, see Schwartz et al. (2009).

Results and discussion

Figure 2 shows the mean overall error rate (left panel), proportion of semantic errors (middle panel), and proportion of form errors (right panel) as a function of number of near and distant semantic neighbors. As predicted, the biggest effect of semantic neighborhoods was on proportions of semantic errors. Data were analyzed using logistic regression with permutations tests of significance[2]. The proportion of semantic errors was greater for targets with many near neighbors ($\beta = 0.5584$, $p < 0.001$) and lower for targets with many distant neighbors ($\beta = -0.4338$, $p < 0.01$). Although the semantic error rate was particularly high for

[1] Detailed anatomical analyses of semantic errors in picture naming by these same patients were recently reported by Schwartz et al. (2009). Due to technical problems, item-level picture-naming data from two of the 64 patients reported by Schwartz et al. were unavailable for analysis, so this analysis included only 62 patients.

[2] The analyses were carried out in R (version 2.10.1, available at http://cran.r-project.org/) using the gmpm package (version 0.4, available at http://r-forge.r-project.org/) for permutation tests. The gmpm package (Barr, 2010) performs permutation tests for multilevel data using the parameter estimates from generalized linear models as test statistics. Parameter estimates for the data set under the original labeling are compared to reference distributions formed by resampling the dataset. Rather than estimating variance components for the model, gmpm controls for them in the method of relabeling observations, which is based on the synchronized permutation approach (Good, 2004; Pesarin, 2001; Salmaso, 2003).

Table 1 Means and standard deviations (*in parenthesis*) for critical and control variables for each of the conditions

	Many near		Few near	
Variable	Many distant	Few distant	Many distant	Few distant
Number of words	12	14	18	13
# Near neighbors	4.3 (3.4)	4.9 (4.7)	0.0 (0.0)	0.0 (0.0)
# Distant neighbors	207 (33.5)	133 (18.8)	226 (51.1)	105 (34.1)
# Features	16.0 (3.7)	15.6 (2.4)	14.9 (2.7)	14.0 (1.7)
Ln(HAL frequency)	8.8 (1.4)	8.8 (1.7)	8.7 (1.2)	8.7 (1.1)
Ln(ANC frequency)	1.1 (0.7)	1.2 (0.6)	1.0 (0.4)	0.9 (0.4)
# Letters	4.9 (1.5)	4.6 (1.5)	5.0 (1.3)	4.9 (1.4)
# Phonemes	4.4 (1.6)	3.8 (1.5)	4.1 (1.1)	4.5 (1.2)
# Syllables	1.8 (0.9)	1.4 (0.8)	1.4 (0.5)	1.4 (0.7)
Orth. neighbors	5.1 (7.0)	4.8 (5.5)	4.4 (4.6)	6.9 (4.7)
Bigram frequency	1,413 (1,251)	1,261 (1,727)	1,073 (814)	1,223 (797)
Phon. neighbors	9.9 (10.4)	12.8 (9.4)	11.7 (10.15)	11.7 (8.1)
Transitional prob.	0.018 (0.016)	0.013 (0.018)	0.020 (0.018)	0.021 (0.012)

targets with many near and few distant semantic neighbors, the interaction was not statistically reliable (β = –0.5124, p = 0.16). There was no effect of distant neighbors on overall accuracy ($p > 0.8$), but targets with many near semantic neighbors had a higher overall error rate (β = 0.1486, $p < 0.01$) and there was a significant interaction (β = –0.2506, $p < 0.05$). Importantly, the semantic neighborhood manipulation had no effect on the proportions of form (phonological) errors (all $p > 0.35$), indicating that the pattern of semantic errors was not due to general difficulty differences between conditions.

A corollary prediction of the opposite effects of near and distant neighbors is that near semantic neighbors should be disproportionately likely to show up as error responses and distant semantic neighbors should be disproportionately unlikely to show up as error responses. This prediction was evaluated by focusing on the 164 error responses that were also in the McRae et al. (2005) corpus, making it possible to evaluate whether they were near or distant semantic neighbors. To compute a chance likelihood of producing a near or distant semantic error, for each of these semantic errors, the proportion of semantic neighbors that met each definition was computed. For example, according to the McRae et al. norms, the concept “van” has 131 semantic neighbors (cosine distance greater than 0); of these, three are near neighbors (cosine distance greater than 0.4), which means that the likelihood of producing a semantic neighbor that is a near neighbor is 3/131 = 0.023 or 2.3%; conversely, 119 of the 131 semantic neighbors are distant neighbors (cosine distance greater than 0.0 and less than 0.25), so the likelihood of producing a distant semantic neighbor is 119/131 = 0.908 or 90.8%. Of the 164 semantic error responses, 42 (25.6%) met the definition of near neighbors (cosine distance to target greater than 0.4) although the mean chance likelihood of producing a near semantic neighbor was only 2.7%. In contrast, 26 (15.9%)

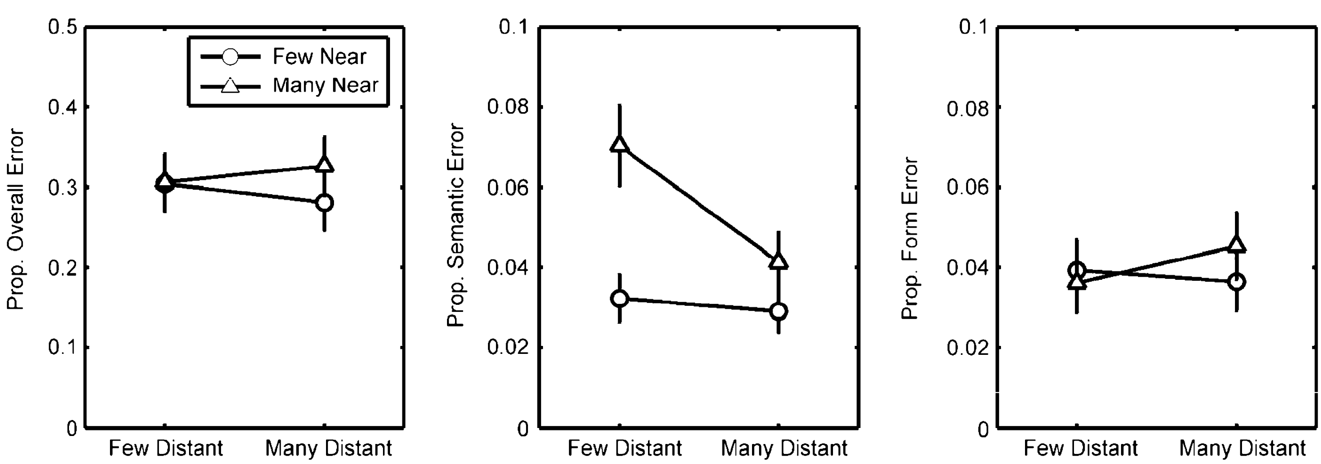


Fig. 2 Effects of near and distant semantic neighbors on errors in picture naming in aphasic patients

met the definition of distant neighbors (cosine distance between 0.0 and 0.25) although the mean chance likelihood of producing a distant semantic neighbor was 91.4%. In other words, semantic errors were nearly ten times more likely to be near neighbors than predicted by chance and approximately five times less likely to be distant neighbors than predicted by chance. These results are consistent with the view that near neighbors exert a detrimental effect on processing because they act as strong competitors and distant neighbors can exert facilitate effects on processing without acting as substantial competitors.

Since the overall group analysis revealed opposite main effects of near and distant neighbors on semantic errors, further individual-level analyses focused on individual patient near and distant effect sizes. For each patient, near and distant semantic neighborhood effect sizes were computed by subtracting the proportion of semantic errors in the two “few neighbors” conditions from the proportion of semantic errors in the “many neighbors” conditions. The near neighbor effect size was marginally negatively correlated with two independent tests of semantic processing: the Camels and Cactus Test ($r = –0.236$, $p = 0.06$) and synonym judgments ($r = –0.222$, $p = 0.08$), indicating that patients with greater semantic impairments exhibited larger detrimental effects of near semantic neighbors. Analogous correlations for distant neighbor effect size were not reliable (both $p > 0.85$).

To gain some insight into the anatomical basis for these effects, correlations between semantic neighborhood effect sizes and percent damage in critical neuroanatomical regions were examined. Brain regions were chosen based on documented involvement in semantic processing and resolution of competition among lexical candidates. In general, semantic knowledge is thought to be widely distributed throughout cortex (for recent reviews see, e.g., Barsalou, 2008; Patterson, Nestor, & Rogers, 2007; Thompson-Schill, 2003), with anterior temporal regions serving as a key “hub” (e.g., Patterson et al., 2007; see also Binney, Embleton, Jefferies, Parker, & Lambon Ralph, 2010; Pobric, Jefferies, & Lambon Ralph, 2010) or semantic-lexical interface (Schwartz et al., 2009). Inferior frontal and temporal-parietal regions are also closely associated with semantic cognition and thought to be involved in cognitive and/or semantic control (e.g., Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Noonan, Jefferies, Corbett, & Lambon Ralph, 2009). More specifically, these three broad groups of brain regions are comprised of the following Brodmann Areas (BA): (1) inferior frontal gyrus (BA 44, 45, 46, and 47), which has been shown to be involved in semantic processing and is particularly important for response selection under competition (e.g., Schnur et al., 2009; Bedny, McGill, & Thompson-Schill, 2008; Novick, Trueswell, & Thompson-Schill, 2005; Snyder, Feigenson, & Thompson-Schill, 2007; Badre & Wagner, 2007); (2) the anterior temporal lobe (BA 38) and middle and superior temporal gyri (BA 21 and 22), which are specifically associated with production of semantic errors by aphasic patients (Schwartz et al., 2009) as well as semantic processing more generally (e.g., Patterson et al., 2007); and (3) the temporal-parietal junction region composed of superior fusiform (BA 37), angular (BA 39), and supramarginal (BA 40) gyri (e.g., Noonan et al., 2009; for a recent meta-analysis of neuroimaging studies of left hemisphere language areas see Vigneau et al., 2006). Lesions were manually drawn by an expert neurologist (for details, see Schwartz et al., 2009). Table 2 shows the results of bivariate correlations and partial correlations controlling for the effect of total lesion volume.

Correlations with distant neighbor effect sizes were substantially smaller than correlations with near neighbor effect sizes, most likely because distant neighbor effects

Table 2 Correlations between semantic neighborhood effect sizes and percent damage to critical neuroanatomical regions

	Bivariate correlations		Partial correlations	
	Effect of near neighbors	Effect of distant neighbors	Effect of near neighbors	Effect of distant neighbors
Total lesion volume	0.178	0.007	–	–
BA 44	0.283*	–0.179	0.224~	–0.251*
BA 45	0.330**	–0.124	0.305*	–0.199
BA 46	0.316*	–0.085	0.266*	–0.115
BA 47	0.240~	–0.083	0.162	–0.130
BA 38	0.285*	–0.080	0.230~	–0.122
BA 21	0.221~	0.009	0.140	0.006
BA 22	0.067	–0.017	–0.047	–0.026
BA 37	0.160	0.199	0.083	0.225~
BA 39	–0.207	–0.046	–0.263*	–0.049
BA 40	0.001	–0.118	–0.111	–0.143

~ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

were generally quite small, so there was very little variability in effect sizes. The strongest effects were a positive correlation between near neighbor effect size and percent damage to BA 45 and BA 46, indicating that patients with more damage to these regions exhibited larger detrimental effects of near semantic neighbors. A similar, though weaker, effect was found for BA 44 and BA 38. The only statistically reliable correlation for distant neighbor effect size was a negative correlation with damage to BA 44, indicating that damage to this region increased the facilitative effect of distant neighbors. There was also an unexpected negative correlation between percent damage to BA 39 and near neighbor effect size, indicating that patients with damage to this area showed smaller detrimental effects of near semantic neighbors.

These results suggest that the effects of semantic neighbors are particularly sensitive to impairments of cognitive control, presumably due to increased difficulty resolving ambiguity and rejecting partially activated distractors. Inferior frontal regions (i.e., BA 44, 45, 46, and 47) are strongly associated with cognitive control and rejection of competing response alternatives (e.g., Schnur et al., 2009; Bedny et al., 2008; Novick et al., 2005; Snyder et al., 2007; Badre & Wagner, 2007). When these regions are damaged, rejecting semantic neighbors may become more difficult, thus the detrimental effect of near neighbors would be enhanced. Damage to brain regions associated semantic processing (BA 38, 39) also affected the magnitude of neighbor effect sizes, though these effects were weaker and more difficult to interpret. Before discussing these issues further, it was important to replicate the basic contrasting effects of near and distant semantic neighbors on picture naming in a different participant group. To that end, study 2 used the same materials and response-scoring procedures, but tested healthy control participants in a speeded naming task to induce errors.

Study 2: Speeded controls

This experiment was designed as a further test of the hypothesis that near and distant semantic neighbors exert opposite effects on word production in picture naming. Building on the aphasic picture naming results of study 1, in study 2 a neurologically intact participant group was tested on the same materials (the Philadelphia Naming Test). Since the critical outcome measure was errors and healthy participants very rarely make errors in picture naming, time pressure was used to induce picture-naming errors. Previous studies have used this paradigm to study errors in word reading (e.g., Kello, 2004; Kello & Plaut, 2000), episodic memory (Balota, Burgess, Cortese, & Adams, 2002), and picture naming (Hodgson & Lambon Ralph, 2008), and it is closely related to speed-accuracy trade-off paradigms (e.g., McElree, 1996).

Methods

Materials The standard PNT pictures were used and the same set of items was analyzed as in study 1.

Procedure The standard PNT was administered in a tempo picture naming paradigm (Hodgson & Lambon Ralph, 2008). This paradigm is based on the tempo word-naming paradigm developed by Kello and colleagues (Kello & Plaut, 2000; Kello, 2004) and aims to induce participants to respond at a particular time after stimulus onset. The participants were instructed that on each trial they would hear a series of three beeps to set the tempo, on the fourth beep they would see a picture, which they were to name in time with when the fifth would occur (there was no fifth beep). Each trial began with the display of a fixation cross accompanied by a series of three beat markers (beeps) presented 500 ms apart. The to-be-named picture appeared simultaneously with the fourth beep and the participant was allowed 1,200 ms to make a response before the next trial began. The 500 ms tempo was chosen because it produced the highest rate of errors in the previous tempo picture naming study (Hodgson & Lambon Ralph, 2008). Tempo accuracy was stressed over naming accuracy. The experiment began with the standard set of 10 PNT practice trials. Responses were recorded to digital audio and scored using the standard PNT scoring procedure, as in study 1.

Participants The participants were 35 healthy older adults with no history of neurological or language impairments and English as the primary language. Participants were approximately matched in age ($M = 59$, *range* = 25–76) and education level ($M = 15$, *range* = 10–21) to the patients reported in study 1.

Results and discussion

The overall mean response time was 702 ms ($SD = 119$ ms), with substantial variability among participants (529–1,072 ms). There were no statistically reliable effects of near or distant semantic neighbors on response time (all $p > 0.15$). The overall accuracy was 90.35% correct ($SD = 5.68$, *range* = 77.71–98.86%), with a relatively low rate of omissions ($M = 2.14\%$, $SD = 2.28$, *range* = 0–9.71%). Semantic errors were the most common error type ($M = 2.64\%$, $SD = 1.79$, *range* = 0–7.43%).

The critical analyses examined the effects of near and distant semantic neighbors by comparing performance for the same four groups of words defined for study 1. Figure 3 shows the mean overall error rate (left panel) and proportion of semantic errors (right panel) as a function of number of near and distant semantic neighbors. Participants made very few form errors ($M = 1.50\%$, $SD = 1.23$, $range = 0–5.14\%$), so this error type was not analyzed. As in study 1, data were analyzed using logistic regression with permutations tests of significance. The speeded controls exhibited the predicted opposite effects of near and distant semantic neighbors on overall accuracy. Targets with many near semantic neighbors had a higher overall error rate ($\beta = 0.514$, $p < 0.001$), and targets with many distant neighbors had a lower overall error rate ($\beta = –0.3222$, $p < 0.05$), and the interaction was not significant ($\beta = –0.2908$, $p > 0.3$). Participants also produced more semantic errors for targets with many near neighbors ($\beta = 1.381$, $p < 0.01$), marginally fewer for targets with many distant neighbors ($\beta = –0.6027$, $p < 0.1$), and the semantic error rate was particularly high for targets with many near and few distant semantic neighbors (interaction: $\beta = –3.0735$, $p < 0.001$).

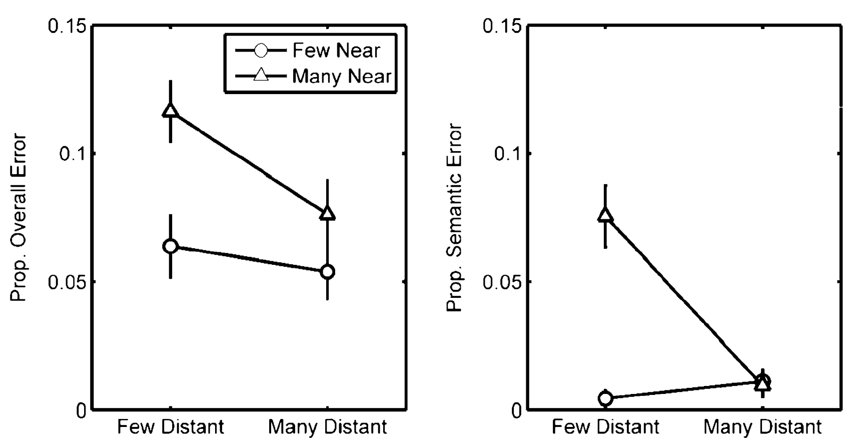
As in study 1, the rates of near and distant semantic neighbors among the semantic error responses were examined. There were 43 semantic error responses that were in the McRae et al. (2005) corpus, of which 27 (62.8%) were near semantic neighbors and 6 (14.0%) were distant semantic neighbors. The average chance likelihood of producing a near semantic neighbor was only 2.4% and the likelihood of a distant semantic neighbor was 93.2%. As in study 1, this pattern of over-representation of near neighbors and under-representation of distant neighbors is consistent with the view that near neighbors exert a detrimental effect on processing because they act as strong competitors and distant neighbors can exert facilitate effects on processing without acting as substantial competitors.

These results provide converging evidence of opposite effects of near and distant semantic neighbors on word production and broadly replicate the critical findings from study 1. Speeded controls were more accurate when naming pictures of concepts that have many distant semantic neighbors and less accurate for concepts with many near semantic neighbors. Like aphasic patients, speeded controls also produced more semantic errors for concepts with many near semantic neighbors and fewer semantic errors for concepts with many distant semantic neighbors. Both groups were particularly prone to semantic errors for concepts with many near neighbors and few distant neighbors, though the interaction was statistically reliable only for the speeded controls. This subtle difference could be due simply to the overall lower error rate for controls.

General discussion

Previous studies found that word recognition was faster for words with many distant semantic neighbors and slower for words with many near semantic neighbors (Mirman & Magnuson, 2008) and related effects for have been found for phonological and orthographic neighbors (Luce & Large, 2001; Andrews, 1996). These opposite effects of near and distant neighbors challenge traditional word processing models, which propose that neighbors exert fixed inhibitory or facilitative effects on processing. Instead, these effects argue for theories based on attractor dynamics, in which the effects of neighbors depend on their impact on the topography of the representational space and the trajectory of settling to the target attractor (Mirman & Magnuson, 2008). This theory was based solely on studies of word recognition, so the present studies examined this account in the domain of word production by testing it in two picture-naming studies. Consistent with the account, in study 1, data from 62 unselected chronic aphasia patients revealed an inhibitory effect of near semantic neighbors (more semantic errors and more errors overall) and a facilitative effect of distant semantic neighbors (fewer

Fig. 3 Effects of near and distant semantic neighbors on errors in picture naming for speeded controls



semantic errors). Study 2 replicated this basic result in neurologically intact controls using a speeded picture-naming paradigm: participants made more errors when naming pictures of objects with many near semantic neighbors and fewer errors when naming pictures of objects with many distant semantic neighbors. Together, the two studies provide strong evidence extending the attractor dynamics view of neighborhood effects from word recognition to word production.

The present demonstration of semantic neighbor effects on picture naming errors raises two additional questions: (1) To what extent are these effects due to disruptions of core semantic knowledge vs. cognitive control of semantic processing? And (2) To the extent that cognitive control mechanisms are involved, what form might those mechanisms take?

Semantic knowledge or cognitive control?

Semantic neighbor effects intuitively take place at the level of core semantic processing and past studies have accounted for these effects on word recognition without any recourse to control mechanisms (e.g., Mirman & Magnuson, 2008). Consequently, it seems reasonable to propose that the observed error patterns are due to disruptions of semantic processing (in the case of aphasic patients) or incomplete semantic processing (in the case of speeded controls). However, there are several reasons to question this account and to propose that the observed patterns are, at least partly, due to disruptions of cognitive control.

First, in anatomical analyses, the strongest correlations were between effect sizes and percent damage in inferior frontal regions associated with cognitive control (BA 46, 45, and 44) and there were smaller correlations with damage in temporal and parietal regions associated with semantic processing (BA 38 and 39). The latter finding is consistent with many studies suggesting that anterior and middle temporal regions play an important role in verbal and nonverbal comprehension (e.g., Binney et al., 2010; Patterson et al., 2007; Pobric et al., 2010). Furthermore, analysis of overall semantic errors in the same patients showed that damage to these regions was most strongly associated with production of semantic errors in picture naming, especially after measures related to cognitive control were taken into consideration, suggesting that this region is particularly important for domain-specific lexical selection processes (Schwartz et al., 2009). Although correlations between percent damage to a region and neighbor effect size should be interpreted cautiously, the stronger relationship between neighborhood effect size and frontal brain regions associated with cognitive control suggests that these effects are due to impairments of cognitive control.

Second, a growing body of evidence shows that semantic processing impairments in aphasia are due to impairments of semantic control rather than semantic knowledge. Much of the most compelling data that support this position come from direct comparisons of aphasia and semantic dementia patients with similar multi-modal semantic impairments (Warrington & Cipolotti, 1996; Jefferies & Lambon Ralph, 2006; Jefferies, Patterson, & Lambon Ralph, 2008; Noonan et al., 2009; Corbett, Jefferies, Ehsan, & Lambon Ralph, 2009a; Corbett, Jefferies, & Lambon Ralph, 2009b). Although both groups of patients show substantial verbal and nonverbal comprehension impairments, their patterns of performance are quite different. Unlike semantic dementia patients, aphasic patients exhibit inconsistent performance across tasks, with particularly poor performance in tasks that require more cognitive control (i.e., more competitors or competitors that are more difficult to reject); benefit substantially from phonemic cues; show much smaller effects of word frequency or familiarity; and produce associative semantic errors in picture naming (e.g., saying "cart" for horse, semantic dementia patients only produce category coordinates, such as "dog", or superordinates, such as "animal"). Gotts and Plaut (2002) provided a related computational account of access/refractory deficits, arguing that performance patterns associated with semantic dementia can be captured by degraded semantic knowledge and patterns associated with aphasia can be captured by changes in neuromodulatory mechanisms (computationally implemented as input and output gain). This combination of behavioral and computational evidence suggests that the semantic dementia patients exhibit disorders of semantic knowledge and aphasia patients exhibit disorders of cognitive control. Although the sample of aphasia patients examined in this study is much broader than just those that exhibit multi-modal semantic impairments, evidence that some aphasia patients exhibit disorders of cognitive control provides further evidence suggesting that the results of study 1, which examined picture naming in aphasic patients, were due to impairments of cognitive control.

Third, previous tempo naming studies suggest that this experimental paradigm affects control processes. Based on their study of memory processes, Balota et al. (2002) argued that time pressure reduced controlled/attentional processes, as in participants with mild dementia. In their tempo picture naming study, Hodgson and Lambon Ralph (2008) found that participants produced associative semantic errors[3] and were sensitive to phonetic cueing—two patterns consistent with disruptions of control and exhibited

[3] In the present study 2, speeded control participants also produced a substantial number of associative semantic errors: 24 of 162 (14%) semantic errors were associatively and not categorically related to the target.

by aphasic patients and not by semantic dementia patients. A more comprehensive analysis was conducted by Kello and colleagues (Kello, 2004; Kello & Plaut, 2000, 2003; Kello, Sibley, & Plaut, 2005) in the domain of word reading. A particular focus of those studies was to distinguish two possible accounts of the effect of time pressure: a threshold account and a rate account. Under a threshold account, processing dynamics are unchanged, but participants lower their threshold for generating a response, thereby allowing earlier responses and increasing error rates (i.e., incomplete processing). Under a rate account, the dynamics of processing are changed. Specifically, the rate of activation is increased, thereby producing earlier responses and increasing the likelihood of an error. In a series of behavioral experiments and computational model simulations, Kello and colleagues showed that the specific error patterns and response durations in speeded word reading were consistent with modulation of input gain (an implementation of the rate account). Furthermore, this input gain account is computationally very similar to the neuromodulatory account of cognitive control impairments in aphasia proposed by Gotts and Plaut (2002).

In sum, (1) analyses of correlations between effect sizes and lesion locations, (2) evidence that semantic impairments in aphasia are due to disruptions of cognitive control, and (3) evidence that the tempo naming paradigm induces similar changes in control dynamics, all provide converging evidence that the picture naming error patterns found in the present studies are due to disruptions of cognitive control mechanisms.

What is cognitive control?

Control processes involved in word processing tasks are typically cast in terms of "lexical selection" or "choosing among competing alternatives" (e.g., Badre & Wagner, 2007; Schnur et al., 2009; Thompson-Schill et al., 1997). The general framework is that multiple lexical or response candidates are activated and the control mechanism needs to choose the correct one. If more candidates are activated or the relative activation of the candidates is more similar (i.e., there is not one candidate that is much more active than the others), this response selection process is more difficult and this increased difficulty is reflected in increased errors for patients or, in functional neuroimaging studies of healthy adults, increased neural metabolic demands by inferior frontal lobe regions responsible for response selection. On this view, impaired cognitive control will make selection among competing alternative more difficult. Since more neighbors will always mean more competitors, this view predicts increasing detrimental effects of neighbors. This prediction is consistent with the detrimental effects of near neighbors, but conflicts with the facilitative effect of distant neighbors. It may be possible that distant neighbors are not active enough to strain the response selection mechanism. In that case, the prediction would be no effect of distant neighbors, but there is no way for a simple response selection mechanism to predict a facilitative effect of distant neighbors.

An alternative to framing control mechanisms in terms of selection is to frame them in terms of responsiveness to input. In computational terms, this is the "input gain" account proposed by Gotts and Plaut (2002) and Kello and colleagues (Kello, 2004; Kello & Plaut, 2000, 2003; Kello, Sibley, & Plaut, 2005). Input gain is a parameter that modulates units' sensitivity to their excitatory and inhibitory inputs. When input gain is low, excitatory and inhibitory inputs have relatively little effect on activation. When input gain is high, inputs have large and rapid effects on activation. Under an input gain account, greater responsiveness to inputs could mean larger inhibitory effects of near neighbors and larger facilitative effects of distant neighbors. Thus, unlike a simple response selection account of cognitive control, the input gain account is consistent with the opposite correlations between near and distant neighbor effect sizes and impairment severity. In an independent set of word recognition studies, simulations of a computational model revealed that modulation of a decision-level gain parameter provided the best account of the time course of word recognition in aphasia (Mirman, Yee, Blumstein, & Magnuson, under review). Based on these results, the proposed account is that detrimental effects of near semantic neighbors and facilitative effects of distant semantic neighbors emerge as a result of attractor dynamics in semantic processing (Mirman & Magnuson, 2008) and these effects are magnified in aphasia and under time pressure due to modulation of a responsiveness (or gain) mechanism of cognitive control. Further computational studies are required to fully evaluate this proposed mechanism.

Conclusions

Two studies found that near semantic neighbors (highly similar concepts) had a detrimental effect on picture naming and distant semantic neighbors (moderately similar concepts) had a facilitative effect on picture naming. These results provide strong evidence consistent with an account of neighborhood effects based on attractor dynamics and extend this account from word recognition to word production. In addition, the results suggest a particular combination of attractor dynamics in semantic processing and modulation of responsiveness due to neurological impairment or time pressure.

Acknowledgements This research was supported by the Moss Rehabilitation Research Institute. Preliminary reports on this research were presented at the 2009 Annual Meeting of the Academy of Aphasia (October, 2009, Boston, MA) and at the 39th Annual Meeting of the Society for Computers in Psychology (November, 2009, Boston, MA). Thanks to Myrna Schwartz for generously sharing the aphasic picture naming data, to Kristen Graziano for her help with data collection and coding, and to Myrna Schwartz and Gary Dell for their valuable comments and suggestions.

Appendix

Stimulus list.

Many Near		Few Near	
Many Distant	Few Distant	Many Distant	Few Distant
squirrel	owl	camel	clock
wagon	church	kite	crown
octopus	scarf	whistle	skis
cow	apple	ruler	closet
house	pie	anchor	slippers
lion	chair	pencil	rope
horse	dog	balloon	pyramid
seal	elephant	drum	belt
harp	goat	rake	bed
bus	knife	pig	lamp
banana	van	tractor	corn
piano	pear	bench	fork
	celery	hose	carrot
	zebra	bridge	
		desk	
		key	
		bread	
		table	

References

Andrews, S. (1996). Lexical retrieval and selection processes: Effects of transposed-letter confusability. *Journal of Memory and Language, 35*(6), 775–800.

Badre, D., & Wagner, A. D. (2007). Left ventrolateral prefrontal cortex and the cognitive control of memory. *Neuropsychologia, 45*(13), 2883–2901.

Barr, D. (2010). Gmpm: Generalized multilevel permutation models (Version 0.4-1).

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.

Bedny, M., McGill, M., & Thompson-Schill, S. L. (2008). Semantic adaptation and competition during word comprehension. *Cerebral Cortex, 18*(11), 2574–2585.

Binney, R. J., Embleton, K. V., Jefferies, E., Parker, G. J. M., & Lambon Ralph, M. A. (2010). The ventral and inferolateral aspects of the anterior temporal lobe are crucial in semantic memory: Evidence from a novel direct comparison of distortion-corrected fMRI, rTMS, and semantic dementia. *Cerebral Cortex*. doi:10.1093/cercor/bhq1019.

Blanken, G., Dittmann, J., & Wallesch, C.-W. (2002). Parallel or serial activation of word forms in speech production? Neurolinguistic evidence from an aphasic patient. *Neuroscience Letters, 325*, 72–74.

Bormann, T., Kulke, F., Wallesch, C.-W., & Blanken, G. (2008). Omissions and semantic errors in aphasic naming: Is there a link? *Brain and Language, 104*(1), 24–32.

Bozeat, S., Lambon Ralph, M. A., Patterson, K., Garrard, P., & Hodges, J. R. (2000). Non-verbal semantic impairment in semantic dementia. *Neuropsychologia, 38*, 1207–1215.

Balota, D. A., Burgess, G. C., Cortese, M. J., & Adams, D. R. (2002). The word-frequency mirror effect in young, old, and early-stage Alzheimer's disease: Evidence for two processes in episodic recognition performance. *Journal of Memory and Language, 46*(1), 199–226.

Corbett, F., Jefferies, E., Ehsan, S., & Lambon Ralph, M. A. (2009). Different impairments of semantic cognition in semantic dementia and semantic aphasia: Evidence from the non-verbal domain. *Brain, 132*(9), 2593–2608.

Corbett, F., Jefferies, E., & Lambon Ralph, M. A. (2009). Exploring multimodal semantic control impairments in semantic aphasia: Evidence from naturalistic object use. *Neuropsychologia, 47*(13), 2721–2731.

Cree, G. S., McRae, K., & McNorgan, C. (1999). An attractor model of lexical conceptual processing: Simulating semantic priming. *Cognitive Science, 23*(3), 371–414.

Dell, G. S., Schwartz, M. F., Martin, N., Saffran, E. M., & Gagnon, D. A. (1997). Lexical access in aphasic and nonaphasic speakers. *Psychological Review, 104*(4), 801–838.

Good, P. I. (2004). *Permutation, parametric, and bootstrap tests of hypotheses*. New York: Springer.

Gotts, S. J., & Plaut, D. C. (2002). The impact of synaptic depression following brain damage: A connectionist account of "access/refractory" and "degraded-store" semantic impairments. *Cognitive, Affective & Behavioral Neuroscience, 2*(3), 187–213.

Hodgson, C., & Lambon Ralph, M. A. (2008). Mimicking aphasic semantic errors in normal speech production: Evidence from a novel experimental paradigm. *Brain and Language, 104*, 89–101.

Ide, N., & Suderman, K. (2004). The American national corpus first release. In *Language resources and evaluation conference (lrec)* (pp. 1681-1684). Lisbon.

Jefferies, E., & Lambon Ralph, M. A. (2006). Semantic impairment in stroke aphasia versus semantic dementia: A case-series comparison. *Brain, 129*, 2132–2147.

Jefferies, E., Patterson, K., & Lambon Ralph, M. A. (2008). Deficits of knowledge versus executive control in semantic cognition: Insights from cued naming. *Neuropsychologia, 46*, 649–658.

Kello, C. T. (2004). Control over the time course of cognition in the tempo-naming task. *Journal of Experimental Psychology: Human Perception and Performance, 30*(5), 942–955.

Kello, C. T., & Plaut, D. C. (2000). Strategic control in word reading: Evidence from speeded responding in the tempo-naming task. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 26*, 719–750.

Kello, C. T., & Plaut, D. C. (2003). Strategic control over rate of processing in word reading: A computational investigation. *Journal of Memory and Language, 48*(1), 207–232.

Kello, C. T., Sibley, D. E., & Plaut, D. C. (2005). Dissociations in performance on novel versus irregular items: Single-route demonstrations with input gain in localist and distributed models. *Cognitive Science, 29*, 627–654.

Lambon Ralph, M. A., Lowe, C., & Rogers, T. T. (2007). Neural basis of category-specific semantic deficits for living things: Evidence from semantic dementia, HSVE and a neural network model. *Brain, 130*(4), 1127–1137.

Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, Instruments, & Computers, 28*(2), 203–208.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: The neighborhood activation model. *Ear and Hearing, 19*, 1–36.

Luce, P. A., & Large, N. R. (2001). Phonotactics, density, and entropy in spoken word recognition. *Language and Cognitive Processes, 16*(5/6), 565–581.

Martin, N., Schwartz, M. F., & Kohen, F. P. (2006). Assessment of the ability to process semantic and phonological aspects of words in aphasia: A multi-measurement approach. *Aphasiology, 20*(2/3/4), 154–166.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I an account of basic findings. *Psychological Review, 88*(5), 375–407.

McElree, B. (1996). Accessing short-term memory with semantic and phonological information: A time-course analysis. *Memory & Cognition, 24*(2), 173–187.

McRae, K., Cree, G. S., Seidenberg, M. S., & McNorgan, C. (2005). Semantic feature production norms for a large set of living and nonliving things. *Behavior Research Methods, 37*, 547–559.

Mirman, D., & Magnuson, J. S. (2008). Attractor dynamics and semantic neighborhood density: Processing is slowed by near neighbors and speeded by distant neighbors. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 34*(1), 65–79.

Mirman, D., Strauss, T.J., Brecher, A., Walker, G.M., Sobel, P., Dell, G.S., & Schwartz, M.F. (under review). *A Large, Searchable, Web-Based Database of Aphasic Performance on Picture Naming and Other Tests of Cognitive Function*.

Mirman, D., Yee, E., Blumstein, S. E., & Magnuson, J. S. (under review). *Theories of spoken word recognition deficits in aphasia: Evidence from eye-tracking and computational modeling.*

Noonan, K. A., Jefferies, E., Corbett, F., & Lambon Ralph, M. A. (2009). Elucidating the nature of deregulated semantic cognition in semantic aphasia: Evidence for the roles of prefrontal and temporo-parietal cortices. *Journal of Cognitive Neuroscience, 22* (7), 1597–1613.

Novick, J. M., Trueswell, J. C., & Thompson-Schill, S. L. (2005). Cognitive control and parsing: Reexamining the role of Broca's area in sentence comprehension. *Cognitive, Affective & Behavioral Neuroscience, 5*(3), 263–281.

O'Connor, C. M., Cree, G. S., & McRae, K. (2009). Conceptual hierarchies in a flat attractor network: Dynamics of learning and computations. *Cognitive Science, 33*(1), 1–44.

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews. Neuroscience, 8*, 976–987.

Pesarin, F. (2001). *Multivariate permutation tests: With applications in biostatistics*. Chichester, England: Wiley.

Pexman, P. M., Holyk, G. G., & Monfils, M.-H. (2003). Number-of-features effects and semantic processing. *Memory & Cognition, 31*(6), 842–855.

Pobric, G., Jefferies, E., & Lambon Ralph, M. A. (2010). Category-specific versus category-general semantic impairment induced by transcranial magnetic stimulation. *Current Biology, 20*(10), 964–968.

Roach, A., Schwartz, M. F., Martin, N., Grewal, R. S., & Brecher, A. (1996). The Philadelphia naming test: Scoring and rationale. *Clinical Aphasiology, 24*, 121–133.

Rogers, T. T., Lambon Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., Hodges, J. R., et al. (2004). Structure and deterioration of semantic memory: A neuropsychological and computational investigation. *Psychological Review, 111*(1), 205–235.

Salmaso, L. (2003). Synchronized permutation tests in 2 k factorial designs. *Communications in Statistics Theory and Methods, 32* (7), 1419–1437.

Schnur, T. T., Schwartz, M. F., Kimberg, D. Y., Hirshorn, E., Coslett, H. B., & Thompson-Schill, S. L. (2009). Localizing interference during naming: Convergent neuroimaging and neuropsychological evidence for the function of Broca's area. *Proceedings of the National Academy of Sciences, 106*(1), 322–327.

Schwartz, M. F., Dell, G. S., Martin, N., Gahl, S., & Sobel, P.(2006). A case-series test of the interactive two-step model of lexical access: Evidence from picture naming. *Journal of Memory and Language, 54*(2), 228–264.

Schwartz, M. F., Kimberg, D. Y., Walker, G. M., Faseyitan, O., Brecher, A., Dell, G. S., et al. (2009). Anterior temporal involvement in semantic word retrieval: Voxel-based lesion-symptom mapping evidence from aphasia. *Brain, 132*, 3411–3427.

Snyder, H. R., Feigenson, K., & Thompson-Schill, S. L. (2007). Prefrontal cortical response to conflict during semantic and phonological tasks. *Journal of Cognitive Neuroscience, 19*(5), 761–775.

Spivey, M. (2007). *The continuity of mind*. New York: Oxford University Press.

Thompson-Schill, S. L. (2003). Neuroimaging studies of semantic memory: inferring "how" from "where". *Neuropsychologia, 41*, 280–292.

Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences, 94*, 14792–14797.

Vigneau, M., Beaucousin, V., Herve, P. Y., Duffau, H., Crivello, F., Houde, O., et al. (2006). Meta-analyzing left hemisphere language areas: Phonology, semantics, and sentence processing. *Neuroimage, 30*, 1414–1432.

Warrington, E. K., & Cipolotti, L. (1996). Word comprehension: The distinction between refractory and storage impairments. *Brain, 119*(2), 611–625.