Neurophysiological mechanisms of reading in alexia: Development of stimuli to examine semantic integration using the N400 response.

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Short Header: Stimulus Creation for Future N400 Study

ABSTRACT

In order for speech-language pathologists to improve therapy for acquired reading impairments, it is necessary to gain a better understanding of how sentences are processed during reading. Neural mechanisms underlying reading processes can be examined by using event-related potentials (ERPs). More specifically, the N400 response is an ERP component that is typically observed in response to semantically anomalous words in a sentence, and appears to be an index of semantic integration and reprocessing. The N400 response is modulated by semantic context, such that the response is smaller when the anomalous word is semantically related to the expected exemplar. Researchers have shown that individuals with alexia display different sentence processing patterns than controls. The purpose of this research project was to develop and norm stimuli for a future study that will examine the N400 response in individuals with and without alexia when reading sentences containing semantic anomalies. Eighty pairs of sentence sets were created to elicit a specific target word (the expected exemplar). An online survey was administered to 89 participants, who were asked to fill in the final word of the sentence in order to examine how well the sentence context facilitated the target word. Eighty sentences were selected based on the mean cloze probability for the expected exemplar (>0.5). The range of cloze probabilities for expected exemplars was 0.5 – 1.0, with an average of 0.86. The sentences developed in this study will be used to gain valuable information about sentence processing in both controls and those with alexia.

INTRODUCTION

Every year, twenty to forty percent of Canadians who experience stroke will acquire aphasia, a language impairment commonly associated with stroke (Dickey et al., 2010; Wade, Hewer, David & Enderby, 1986). Many of these individuals will also have acquired reading impairments that can impact processing of single words, sentences, and/or larger texts. Webb and Love (1983) found that among thirty-five patients with aphasia, all of the patients had some difficulty with reading. Impairment of literacy abilities can be detrimental to many individuals and their quality of life, and addressing these impairments is an important part of rehabilitation. In order to understand how to successfully treat reading impairments, it is necessary to understand the cognitive components involved in reading, as well as how reading can be disrupted due to brain trauma. Researchers continue to further our understanding of the cognitive components that comprise reading in individuals without reading impairments. However, there is still not a complete description of these processes. Furthermore, it is even less well understood how the neurological damage that can lead to aphasia and alexia impacts the various reading processes. Thus, further investigation into the neurological components involved in normal and disordered reading is crucial to developing a thorough understanding of the processes and how to treat impairments of reading.

Language Impairment and Sentence Reading

Contextual information affects reading in both individuals with and without language impairments. The term “contextual information” refers to the way that words are embedded in sentences or in texts. It has been theorized that reading words may be facilitated by syntactic or semantic constraints (Beeson & Insalaco, 1998; Mitchum, Haendiges & Berndt, 2005; Silverberg,

Vigliocco, Insalaco & Garrett, 1998). For example, when reading the sentence “I washed the dishes”, correct identification of the word “dishes” is facilitated by the semantic knowledge of items that are associated with the word “washed”. Silverberg and colleagues (1998) examined the role of sentence context in the reading of patients with deep dyslexia. Deep dyslexia is a disorder characterized by visual reading errors (e.g. mistaking the word “think” for “thing”), semantic reading errors (e.g. mistaking the word “bird” for the word “canary”), and difficulty reading function words (e.g. “the”) (Coslett, 2000). Interestingly, individuals with deep dyslexia were significantly more accurate when reading function words (e.g. “the”) in text format rather than a list format (Silverberg et al., 1998). There was no similar effect of increased accuracy for content words (e.g. “go”). Silverberg et al. suggested that this effect was due to the constraining grammatical cues provided by the sentence that allowed patients to read the correct function words in texts with greater accuracy. Furthermore, individuals with aphasia and comprehension deficits were often better able to distinguish words when read in sentences as compared to lists (Mitchum et al., 2005). This pattern seemed to be related to these patients' abilities to predict words based on the grammatical features provided by the sentence context. Mitchum and colleagues (2005) further theorized that this grammatical knowledge was combined with orthography and imageability to decrease the number of plausible responses.

The theory that context induces a facilitation effect is further supported by research regarding eye movements. For example, Kim and Bolger (2012) found that for individuals with aphasia, “high context sentences” (i.e. those where words were more predictable based on other words in the sentence) resulted in more efficient eye movements than did low-context sentences (i.e. those where words were not predictable based on the sentence context). Based

on the available research, it is clear that sentence context affects sentence processing in individuals with acquired alexia. However, the neurophysiological underpinnings of this effect remain unclear.

EEG and the N400 Component

One way in which the neurophysiological mechanisms of reading and the effects of sentence context on reading performance can be examined is through electroencephalography (EEG) and event-related potentials (ERPs). This technology involves recording neural activity through the scalp, and temporally aligning these recordings with a specific event such as the presentation of a specific word in a sentence (Federmeier & Kutas, 1999; Kutas & Hillyard, 1980). The temporal resolution provided by ERP has been particularly useful for elucidating the mental processes that occur during sentence processing in both healthy control subjects and those with acquired alexia.

A specific ERP component, the N400 response, has been utilized extensively with respect to sentence context effects (Kawohl et al., 2010). First documented by Kutas and Hillyard in 1980, the N400 was described as a "negative component beginning at about 250 [milliseconds (msec)] and peaking at about 400 msec after stimulus onset" (pp. 203). The N400 response is thought to represent the brain reprocessing semantically unexpected material. Kutas and Hillyard (1980) first demonstrated this component by having participants read sentences word by word, with some sentences ending in a word which was semantically incongruous with the rest of the sentence (e.g. "I take coffee with cream and **dog.**"). The sentences ending with unexpected words were associated with an N400 effect in the frontal, central, and parietal regions, which Kutas and Hillyard (1980) hypothesized to reflect the interruption of processing

caused by the unexpected word. Further research into the anatomical location of the N400 response showed the most prominent responses in the right medial parietal area (e.g. Federmeier & Kutas, 1999; Kutas & Van Petten, 1994). That being said, the N400 is not thought of as characteristic of one particular brain area or mental process; instead, it is better defined as a specific response to unexpected information (Kutas & Federmeier, 2011).

Since this landmark study, the N400 has been investigated many times. The results of numerous studies have established the N400 as an ERP component that reflects semantic integration and reprocessing (e.g. Kuperberg, 2007; Van Petten & Luka, 2012). Van Petten and Luka (2012) concluded that, when listening to sentences, subjects continuously integrate the input they are receiving, which leads to an expectation about the semantic information that will follow next. This conclusion was based on a meta-analysis of multiple studies of sentence processing. Furthering this description, Federmeier and Kutas (1999) explained that as one reads or listens to a sentence, the semantic context is continually processed and updated. This then leads to the activation of a certain group of semantic features that are expected to follow. Thus, semantic information is integrated together as one processes a sentence, resulting in neural activation of the semantic features of the word that is expected to follow. If the next word is unexpected, or anomalous, the brain must reprocess the semantic information, resulting in the N400 response (e.g. Federmeier & Kutas, 1999; Kutas & Hillyard, 1980).

Researchers have shown that the N400 effect is influenced by semantic category (e.g. Federmeier & Kutas, 1999; Kutas & Hillyard, 1980; Kutas & Van Petten, 1994). For example, the N400 differs between words coming from the same semantic category as the expected word (within-category violations) and words coming from different semantic categories (between-

category violations) (Federmeier & Kutas, 1999; Kutas & Federmeier, 2000). An example of a within-category violation would be "Checkmate, Rosaline announced with glee. She was getting to be really good at **monopoly**." In this example, the reader expects the word "**chess**", so the word "**monopoly**" is a violation from the same semantic category (board games). A between-category violation would be if that same sentence ended in the word "**football**", which is from the semantic category of sports. Federmeier and Kutas (1999) concluded that N400 responses were larger in response to between-category violations than within-category violations.

The finding that N400 response size varies with semantic category relations is hypothesized to be related to the structure of the long-term memory (LTM) system for semantic knowledge (Federmeier & Kutas, 1999; Kutas & Federmeier, 2000). The LTM system stores concepts in such a way that related semantic features overlap, allowing for multiple possible word choices for a given circumstance (Federmeier & Kutas, 1999). In this case, within-category violations have more semantic feature overlap with the expected exemplar than do between-category violations. This increased overlap leads to a relative ease of processing for the within-category violation, resulting in a smaller N400 component. Thus, there are different degrees of facilitation provided by the sentence context. The expected exemplar yields the largest processing benefit, reflected by the absence of an N400 response, followed by the within-category violation, and finally the between-category violation (e.g. Federmeier & Kutas, 1999; Kutas & Hillyard, 1980; Kutas & Van Petten, 1994).

Acquired Reading Impairments and the N400 Effect

Information about the N400 response in individuals without language impairments is valuable for developing an understanding of reading processes. However, the N400 response

can also be used to examine reading processes in individuals with acquired alexia in order to further understand the neurological deficits these individuals experience. For example, Brandeis and Lehmann (1994) found that the N400 effects were correlated with the degree of word comprehension deficits in subjects with aphasia. In line with this, a study by Hagoort, Brown, and Swaab (1996) found that individuals with aphasia who had minor comprehension deficits were not significantly different from controls in terms of the N400 response to semantically incongruent words. In contrast, those with more severe deficits showed reduced N400 responses. A recent study by Kawohl et al. (2010) further elaborated on the differences in processing between individuals with aphasia with mild versus severe comprehension deficits. Using ERP recordings, they found that the individuals with aphasia and *severe* comprehension deficits had no N400 after the presentation of semantically incongruent words. This lack of response to semantic incongruities was thought to be due to a failure to perform semantic integration. Conversely, those with aphasia and *mild* comprehension deficits did display an N400, although with a prolonged latency compared to controls. This prolonged latency was hypothesized to reflect slower semantic processing in participants with mild comprehension deficits, as compared to controls. Furthermore, by comparing individuals with aphasia to individuals without aphasia who had right hemisphere lesions, they were able to conclude that the differences in N400 response were not simply the result of damage to the brain, but instead related to damage of specific language comprehension areas typically found in the left side of the brain. Overall, these studies have led to the conclusion that individuals with aphasia and alexia following damage to language comprehension areas have impaired semantic integration, resulting in absent or delayed N400 responses to semantically incongruent words.

Summary

As discussed above, individuals with alexia display different language processing patterns than controls (i.e. Kawohl et al., 2010). Further investigation of cognitive and neural mechanisms underlying reading processes is necessary to develop effective treatments and refine models of written language processing. The purpose of this study was to develop and norm stimuli for a study that will examine N400 effects in individuals with and without acquired alexia when reading sentences containing semantic anomalies. The current paper will detail the creation and norming of the stimuli.

METHODS

Participants

Participants included 89 individuals (66 women, 19 men) between the ages of 16 and 86 (mean=26 years) who were recruited through social media and email. The education levels of participants included: bachelor's degree (42.7%), technical degree or some post-secondary education (34.8%), post-graduate degree (11%), and high school diploma (10%). The study was approved by the Ethics Board at the University of Alberta. Participants were not compensated for their participation. All participants consented to participate based on the informed consent form found in Appendix A.

Materials

The stimuli creation methods employed in this study were based on the methods outlined in Federmeier and Kutas (1999). Forty pairs of 3-8 letter target words (e.g. nurse and doctor; judge and lawyer) were chosen based on their Thorndike-Lorge written frequency (0 to 200,000), concreteness rating (460 – 700) and imageability rating (460 – 700) (Thorndike &

Lorge, 1944). A complete list of these words can be found in Appendix B. These pairs of words represented 40 different categories (i.e. nurses and doctors are both medical professionals, judges and lawyers are both law professionals). Each category was grouped with another, semi-related category to create a superordinate category (i.e. nurse, doctor, judge, and lawyer are all professions). These groupings are shown in Appendix C. Based on this categorization method, expected and within-category final words were chosen from one category (i.e. medical professionals), and the between-category item came from the other pair within the superordinate grouping (i.e. professionals). For example, the word "nurse" would serve as the anomalous and semantically related target for the sentence created for the word "doctor", while the word "judge" would serve as the semantically unrelated, or between-category, violation. 160 sets of paired sentences were created for each of 80 different target words. Examples of the stimuli sentences can be found in Appendix D. The first sentence was designed to serve as general context (i.e. "Eleanor offered to fix her visitor some coffee") and to create an expectation for the target word at the end of the second sentence, based on the item and category. The target word differed across three stimulus types:

1. Expected word: a word that is most likely to complete the second sentence based on the initial context sentence.
    a. E.g. "Then she realized she didn't have a clean *cup*."
2. Anomalous but semantically related word: a word that is not expected to complete the sentence, but is semantically related to the most expected word.
    a. E.g. "Then she realized she didn't have a clean *bowl*." A cup is similar to a bowl in that both are used to contain food.

3. Anomalous and semantically unrelated word: a word that is neither expected to complete the sentence, nor semantically related to the expected word.
    a. E.g. “Then she realized she didn’t have a clean *fork*.” A fork is not capable of containing food.

The expected exemplars chosen for this study were required to have a cloze probability greater than or equal to 0.5 (i.e. above chance levels). This threshold was chosen in order to ensure that the context sentence at least partially facilitated the expected exemplar, and also to constrain the amount of variability in the degree of facilitation provided by the context sentence. Expected exemplars were also required to be the item with the highest mean cloze probability from the sample, to ensure that more readers were led to that particular final word than any other possible completion.

In addition, 40 pairs of filler sentences were created based on the original list of words with equivalent imageability ratings. These sentences were created to be control stimuli with the expected exemplar as the final word. These sentences were randomly dispersed throughout the stimulus sentences in the ERP study, such that there will be an equal number of expected and unexpected sentence-final words. The filler stimuli created for this study can be found in Appendix E.

Procedure

Two online surveys were created for the purpose of generating norms for the cloze probability of stimuli materials. Participants were presented with sentence stimuli with the final word missing. They were instructed to fill in a text box with the word that first came into their mind to complete the final sentence. Stimulus items containing matching pairs of words did not

appear in the same survey version. Items appearing in the same survey with words from the same basic category were separated by at least two pages of items in order to ensure that the participants were not primed to reproduce certain responses (i.e., one was likely to enter "nurse" as a response because they had just entered "nurse" in a previous question).

RESULTS

Survey distribution resulted in 89 complete sets of responses. The mean cloze probability for all expected exemplars (excluding filler sentences) was 0.86. Actual cloze probabilities for expected exemplars ranged from 0.5 to 1.0 for selected sentence contexts. The mean cloze probability for all within-category violations was 0.014, and the range was 0 to 0.24. Between-category violations had cloze probabilities between 0 and 0.041, and a mean of 0.0016. Appendix F displays the cloze probabilities for within and between-category violations.

Four target items required editing and re-norming after the first dataset was collected, as they did not reach a cloze probability of 0.5. These items were *state*, *wife*, *club*, and *city*. New sentences were created for each of these items, and a new survey was created following the methods used for the original surveys. This new survey was administered to ten individuals based on convenience sampling. The average cloze probability for these new four items was 0.88, ranging from 0.5 to 1. Final words that were within-category and between-category violations all had cloze probabilities of 0. Adding these re-normed values into the original set, the revised mean cloze probability for expected exemplars was 0.86. An additional thirteen filler sentences were required, and these items were also included in the second survey. The target words for the additional filler sentences were *powder, station, ship, roof, railway, race, oven, oil,*

news, owner, motor, money, and *meal*. All of these items and their cloze probabilities can be seen in Appendices D and E.

DISCUSSION

This paper detailed the importance for further examination of the neurophysiological underpinnings of sentence processing in those with aphasia and acquired alexia. The purpose of the current study was to develop and norm stimuli for a later study that will examine N400 effects in individuals with and without acquired alexia when reading sentences containing semantic anomalies. These stimuli were created following the protocol outlined in Federmeier and Kutas (1999). Based on survey responses from 89 participants, 80 sentences were selected out of a set of 160, with the addition of 40 filler sentences. Sentences were selected based on the mean cloze probability for the expected exemplar. The range of cloze probabilities for expected exemplars collected from this study was 0.5 – 1.0, with an average of 0.86. The range for within-category violations was 0 - 0.24, and the range for between-category violations was 0 – 0.041.

The range in cloze probabilities indicates that the sentences used in this study varied in the amount to which they led the reader to a certain final word (i.e. some sentences are more constraining than others). For example, a sentence with a final word that has a cloze probability of 1.0 leads the reader very strongly towards that particular final word. A sentence with a final word with a cloze probability of 0.5 is less predictive of that exact final word. Federmeier and Kutas (1999) compared high cloze probability (mean = 0.896) with low cloze probability (mean = 0.588), and found that higher cloze probability resulted in increased ease of prediction. As the mean cloze probability for expected exemplars in this study is 0.86, it is likely that these stimuli

fall under the high cloze probability category. Furthermore, the range of cloze probabilities for the within and between-category violations shows that the chosen sentences are unlikely to lead readers to predict the anomalous endings. Additionally, readers were more likely to predict the within-category violations than between-category ones. This is expected, given knowledge of semantic feature overlap in the long-term memory.

A firm understanding of the mechanisms underlying language processing in both healthy individuals and individuals with alexia due to stroke is necessary to develop evidence-based treatments. The stimuli creation and norming detailed above will be used for a subsequent study of semantic context and sentence processing in people with and without alexia. The information gained about neural mechanisms underlying sentence processing in both controls and those with aphasia will aid in building a strong foundation upon which treatment methods can be built.

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APPENDIX A

Information Letter and Consent Form

INFORMATION LETTER

Study Title: Neurophysiological mechanisms of reading in aphasia: Context effects and response to treatment

Research Investigators: Megan Donnelly& Melissa Kinsman, MSc-SLP students
Esther Kim, Ph.D., R-SLP, CCC-SLP, Assistant Professor
Jacqueline Cummine, PhD, Associate Professor

Background and Purpose: People with aphasia (a language problem after stroke) often have a hard time reading and understanding what they've read. We want to study what kinds of things affect reading, and what kinds of things can help people with aphasia to become better at reading. You are being asked to participate in a research study because you are a healthy control who has not had any kind of brain injury. You will be helping us develop the materials that people with aphasia will be reading.

Procedures: If you agree to take part in the study, you will access an online survey link where you will read two sentences. The second sentence will have one word missing. You will write in a word that you feel completes the sentence so that it makes sense. The study will take about 20 minutes to complete. Submitting the survey implies your consent to participate in the study.

Possible Benefits and Risks: There are no risks to taking part in the study. By participating, you are contributing to the research on how individuals read and understand sentences.

Confidentiality: All information collected will be confidential. You will be identified only by a number. All collected information will be kept secure at all times on a protected computer, which is kept behind locked doors when unattended. The researcher will keep all information safe for a period of at least 5 years.

Voluntary Participation: You have the right to refuse to take part in any of the activities. You are also free to stop being in the study at any time, without any bad feelings.

Contact Names and Telephone Numbers: If you have concerns about this study, you may contact the Research Ethics Office, at 492-2615. This office has no direct involvement with this project." This office has no affiliation with the study investigators. You can also contact the individual identified below if you have any questions or concerns:

Principal Investigator
Dr. Esther Kim, Assistant Professor, Department of Communication Sciences and Disorders
Phone: (780) 248-1542 Email: esther.kim@ualberta.ca

APPENDIX B

Words Used in the Experiment

The following table displays the 80 different words which were used in this experiment as well as each word's Thorndike-Lorge written frequency (Thorndike & Lorge, 1944), and a rating of concreteness and imageability.

Target word	Thorndike-Lorge written frequency	Concreteness Rating	Imageability Rating
bear	605	585	572
brain	401	556	572
bus	125	-	-
carrot	96	622	577
chair	1298	606	610
chicken	357	614	619
city	1258	554	605
club	999	509	522
coffee	580	613	618
cotton	577	608	562
couch	108	578	536
ear	595	640	597
eye	5786	634	603
field	661	-	-
fish	597	597	615
flute	13	587	581
hill	335	588	607
judge	638	506	558
juice	463	599	593
lawyer	417	569	557
lizard	12	588	632
mouse	48	624	615
park	647	579	573
potato	384	629	617
principal	139	381	402
rock	509	600	612
silk	865	520	534

snake	62	621	627
spine	50	-	-
squirrel	32	612	642
summer	783	439	618
tea	484	609	599
teacher	356	569	575
town	1607	556	553
train	1019	592	593
trumpet	37	608	628
water	2067	616	632
winter	610	499	621
wolf	121	595	619
yard	481	553	568

APPENDIX C

Categories Used in the Experiment

The following table displays the 40 different categories which were used in this experiment.

Category pairs are shown across rows.

Superordinate Category	**Basic Category 1**	**Word Pair 1**	**Basic Category 2**	**Word Pair 2**
People	family	husband/wife	school professions	principal/teacher
	Health professions	doctor/nurse	law professions	judge/lawyer
Body parts	oral tract	mouth/throat	nervous system	brain/spine
	extremities	foot/hand	face	eye/ear
Places	inside places	room/hall	outside places	yard/park
Instruments	strings	guitar/violin	wind	flute/trumpet
Food	dairy	cream/butter	drinks	tea/coffee
	seasonings	sugar/salt	meat	fish/chicken
Nature	weather	rain/snow	seasons	summer/winter
	bodies of water	lake/river	land	hill/field
Materials	precious metals	gold/silver	fabrics	cotton/silk
Animals	domestic	cat/dog	wild	bear/wolf
	birds	owl/eagle	reptiles	snake/lizard
Weapons	man-made	gun/bomb	natural	club/rock
Foods	citrus fruits	lemon/orange	vegetables	potato/carrot
	alcoholic drinks	wine/beer	non-alcoholic	juice/water
Locations	geographical	state/country	municipalities	town/city
Furniture	surfaces	table/desk	seating	chair/couch
Transportation	personal	car/truck	public	bus/train
Pests	insect	bee/ant	rodent	mouse/squirrel

APPENDIX D

Sentences and Cloze Probabilities

Probability	Stimulus	Target Word
0.9	As a kid, he used to enjoy watching them march in a file, carrying objects many times their weight. He imagined life would be hard as a small...	ant
1	The grizzly stood up on his hind legs and roared at the campers. They had never expected to be attacked by a...	bear
0.95	At halftime, Carmen went to see if there was another six-pack in the cooler. Unfortunately, they were already out of...	beer
1	I love their honey but am always afraid to be stung. That's why I always keep my distance from...	bees
0.83	On August 6, 1945, the United States detonated "Little Boy" over Hiroshima. At the time, it was the newest type of...	bomb
0.66	Humans are much smarter than elephants. However, compared to a human an elephant has a much bigger...	brain
0.92	Before the civil rights movement, African Americans suffered much discrimination. For instance, they were made to sit at the back of the...	bus
0.92	"You've got to churn it harder than that!" Phil exclaimed. He wanted to make high-quality...	butter
0.82	My Volkswagen needed a new transmission, steering column and tires. I think it's time for a new...	car
0.98	It was a perfect winter day to be building a snowman. The nose was the missing piece, so I looked all around for the...	carrot
0.63	Our pet tabby was originally a stray. We were out hiking in the woods one day and came upon a lost...	cat
0.71	When Sarah's party of 5 arrived at the restaurant, one of them had nowhere to sit. They requested an extra...	chair
0.94	The farm next door had recently slaughtered a whole coop. Jamie went over to buy some...	chicken
1	Six months ago, Charlie had moved to Vancouver, British Columbia from Vermilion, Alberta. He was finding it hard to get used to living in such a big...	city
0.5	The caveman knew his weapon couldn't win a fight with the creature. After all, all he was wielding was a blunt, wooden...	club
0.84	Marshall had been studying all night for his exam and decided that he needs something to stay awake. He made himself some...	coffee
0.86	Her brand new t-shirt shrunk in the wash. She should be more careful when washing items made of...	cotton
0.92	George's living room was so barren, there was only a TV. Guests always complained that he should buy a...	couch
0.95	During his attempted invasion of Russia, Napoleon discovered that it was very large. In fact, it's the biggest...	country
0.90	While biking home from school, I realized that I'd forgotten my homework in the classroom. I rushed back to find it sitting on my...	desk
0.88	Tim had been having abdominal pain for three days, so finally went to the hospital. He thought he should be seen by a...	doctor
0.85	Rocky was always burying bones in the backyard. He really was a stereotypical...	dog
0.93	America prides itself in being a country of independence and freedom. That's why their symbol is a majestic...	eagle
0.88	Marvin's favourite animal is a rabbit. He wonders why they have such large...	ears

0.95	Gloria has to squint when the sun is too bright. She feels more comfortable with something to cover her...	eyes
0.93	Sammy was learning how to play soccer. He learned that he was only allowed to use his...	feet
0.6	They were painting lines on the grass during our soccer practice. We had to stay off the...	field
0.92	The men pulled the heavy net onto the deck of the boat. They were glad to see it was full of...	fish
0.78	She blew across her instrument so gently it sounded like a bird song. It was clear she had mastered the...	flute
0.74	He enjoyed the traditional make of his wedding band. He would have been disappointed with anything other than...	gold
0.83	Jeff was strumming and singing on the subway platform. He made pretty good money playing the...	guitar
0.86	During his first deployment, the soldier always hesitated before shooting. He was nervous to use his...	gun
0.98	When the bell rang, the students all streamed out of the classrooms to their lockers. It was very crowded in the...	hall
0.94	The referee blew his whistle at Luke during the soccer game. Luke had accidentally used his...	hands
0.85	Every winter the family loved going tobogganing. They lived near the best...	hill
0.80	She always knew she could count on him to have supper ready after work. That was one of the many reasons she loved her...	husband
0.75	The prisoner stood in the courtroom for his sentencing. “You should be ashamed of yourself,” said the...	judge
0.98	Carlos liked to get a good dose of vitamin C in the morning. So, he poured himself a tall glass of...	juice
0.83	The calm waters made it ideal for Jake to go fishing. He was lucky to be so close to a...	lake
0.96	This case would require all his legal knowledge to defend. This would be his greatest test as a new...	lawyer
0.80	In the summer, she loved to drink iced tea. It was especially delicious with a wedge of...	lemon
0.71	The scaly reptile crawled onto the rock, stretching its foot into the hot, desert sunlight. This was the first time I’d ever seen that type of...	lizard
1	Dean went up to the cow with a bucket. He wanted to get some...	milk
0.92	I knew I could trap this creature by putting out some cheese. Once I did this, it was easy to catch the...	mouse
0.85	“Open wide” said the dentist. Sarah couldn't help that she had a small...	mouth
0.68	Lisa carefully checked the patient's vital signs and administered the medication. She thought about how lucky she was to have a job as a...	nurse
0.94	Tropicana is my favourite brand of juice. On the box is a picture of a fresh...	orange
0.85	Tiptoeing through the forest at night, Livingston heard an eerie hoot from a nearby tree. He guessed that the sound came from a nearby...	owl
0.98	The new off-leash area attracted many dog-owners. I’d never seen so many people in the...	park
0.96	David didn’t care if they were boiled, mashed, fried, baked, or roasted. He felt no meal was complete without some...	potatoes
0.56	Mrs. Brown was always strict with the trouble-makers who came to her office at school. This made her a good...	principal
0.95	The couple ducked under their umbrella to avoid getting wet. They were having so	rain

	much fun they didn't mind walking in the...	
0.78	Karen was an adrenaline junkie who really enjoyed rafting. You could find her every weekend on the...	river
0.63	The caveman had run out of ammo for his slingshot. He reached into his sack for another...	rock
0.86	The metal device in his bag had set off the metal detector at the airport. He was led away by a guard and asked to wait in another...	room
0.88	The chef wanted to make sure his pasta was not too bland. Once the water was boiling, he added...	salt
0.96	She owed the smoothness of the dresses she made to the worms who spun the fabric. She only ever used...	silk
0.54	His car was a shiny metallic grey colour. Of course, he still knew that it was not made out of...	silver
0.98	The creature slithered in its cage, hissing at me with its forked tongue. I recoiled, terrified of the...	snake
0.94	It was a whirlwind of white, powdery fluff. The children loved playing in the...	snow
0.88	Amy grew up with scoliosis and had to wear a back brace. This was due to her deformed...	spine
0.94	At the end of fall, you could see them scouring the earth for nuts before the winter settled in. This crucial period determined the survival of the...	squirrels
1	Michael just loved living in Florida. Even though he liked all of the USA, he knew he would always live in that...	state
0.96	Scott liked his coffee very sweet. He always kept his kitchen well-stocked with...	sugar
0.83	The freshly picked berries were still warm from the sun. They were her favourite food to eat in the...	summer
1	Mrs. Smith called out to her family that dinner was ready. They quickly ran downstairs and sat at the...	table
0.80	Lily stared at her drink longingly as it steeped on the kitchen counter. She was eager to drink her cup of...	tea
0.96	Mr. White spent lots of time playing games with his class. This is why all the children wanted him as their...	teacher
1	John went out to buy a bag of cough drops. He had been suffering from a sore...	throat
0.9	Moving to New York from rural Kansas made her nervous. She has always lived in a small...	town
0.94	My mother took a trip across Canada on the VIA rail. She saw the most beautiful landscapes from the window of the...	train
0.73	Jack was excited about buying himself a treadmill, but wondered how he'd get it back to his house. He called Ben, the only person he knew who owned a...	truck
0.62	Every morning, the soldiers were woken by the same blaring song. Their least favorite instrument was now the...	trumpet
0.58	Angela bought a new bow for her big orchestra solo. She was well-known for playing the...	violin
0.90	The triathlon had been a grueling four hours in the hot sun. Upon crossing the finishing line, the runners immediately began to drink...	water
1	"You may kiss the bride!" the minister told the groom. With this action, she was officially his...	wife
0.94	Cecil sent back the bottle of 2010 Pinot Noir the waiter had brought him. He was very particular about his...	wine
0.98	The forest animals had already started gathering food in preparation for colder days. It promised to be a long...	winter
0.92	He looked on in awe as the lone animal howled at the moon. His favourite animal	wolf

	was always the...	
0.68	Jacob mowed his lawn and trimmed the hedges. As a result, it was a nice-looking...	yard

APPENDIX E

Filler Sentences and Cloze Probabilities

Probability	Stimulus	Target Word
0.95	It had been the worst drought in history, with no rain for weeks. In these conditions, even a tiny spark could start a...	fire
0.66	Ashley's grandma suggested that she should write down every day's events during her trip abroad. Ashley decided she would keep a...	journal
0.98	At the end of the night, Teresa smiled as her date leaned in with puckered lips. She had been hopeful for a...	kiss
0.68	Due to the car accident, Sarah had to hobble around on crutches but at least she wasn't in a wheelchair. She was lucky that she had only broken one...	leg
0.9	After coming home from college, John was excited to see that his mom had made meatloaf and mashed potatoes. This had always been his favorite…	meal
1	The entrepreneur valued his growing fortune more than his growing family. He had forgotten that there are more important things in life than...	money
0.4	Even though it was plugged in, the electric fan wouldn't spin. It must be due to a broken...	motor
1	Matt liked to stay informed of current events. Every morning, he would watch the...	news
0.9	A small light lit up on the dashboard when she started the car. Looks like it's time to change the...	oil
1	David wanted to eat the cookies he made, but they were still too hot. He had just pulled them out of the...	oven
0.9	Rose had found a lost puppy wandering around outside her house earlier. She took it in and immediately tried to find its...	owner
0.86	Heather spent all night packing for her big trip to Europe. She had to leave early in the morning to board the...	plane
0.96	The pirate captain did not stand for mutineers. Therefore, he forced the rebels to walk the...	plank
0.68	Jean and Doug loved to spend summer afternoons in their rockers, drinking ice tea. The neighbours would often see them sitting out on their...	porch
1	Maria stood in the aisle, looking at the displays. There was a sale on laundry detergent and she was trying to decide between liquid or...	powder
0.51	As Cliff answered the final question, cheers erupted from the audience and he knew he'd won. The host shook his hand and presented him with the...	prize
1	Bob tried not to get too excited as the finish line came into view and he was still in first place. He had run so well, you would never guess that this was his first...	race
1	As part of the history course, the class was taking a train trip across Canada. There were very excited to learn all about the Canadian Pacific...	Railway
1	John enjoyed decorating the house with lights during the holiday season. He was always sure to carefully secure the ladder before climbing on the...	roof
1	The morning breeze was ideal for taking out the boat. It wasn't long before the boat took off as the wind caught the...	sail
0.6	In lieu of the upcoming wedding, Jane was trying to lose weight. Each day for lunch and dinner she only ate a…	salad
0.73	When she makes spaghetti, it usually takes all day. It takes a long time to simmer the….	sauce
0.73	The director cried "cut" after the actors were done. He did this at the end of every…	scene

0.85	Mary has a fear of heights, spiders and small spaces. She's practically afraid of her own…	shadow
0.88	Martin wanted to be a ghost for Halloween. He cut two big holes out of a white...	sheet
1	Many early settlers came over from Europe on the Mayflower. It must have been a hard few months before they arrived in New York, living on a...	ship
0.88	I ordered pepperoni pizza for dinner -- Joey's favourite. When Joey came over, I offered him a…	slice
0.66	Today, my sister's boyfriend broke up with her, sending her into a pit of despair. At night, from her room, I heard a quiet…	sob
0.78	The basil plant on my windowsill had finally sprouted. A single, green stem poked out from the...	soil
0.86	From Shreddies cereal, to Saltines, to toast, to lemon bars -- I'll eat them all. I love food in the shape of a…	square
1	Henry was worried he would be late and miss his train. Luckily, he arrived just in time to see the train pull into the...	station
0.94	At first, the little girl excitedly reached out for the goodies the unfamiliar man was offering to her. But then she remembered her mother telling her to never take candy from a….	stranger
0.61	Mike got a job as a lawyer for one of the top firms in Manhattan. He was told to go out and buy a new…	suit
1	Every summer she looked forward to her family's vacation to the coast. Her favorite pastime was lying on the beach, soaking up rays from the…	sun
0.62	Some proposed increasing it for the rich while others argued that it would scare them away. No one seemed to agree on the…	taxes
0.52	George wasn't allowed to board the ferry without it. But wherever he looked, he just couldn't find his….	ticket
0.96	Robin had visited Thailand, Singapore, Malaysia and Laos in the past month. He really liked to…	travel
0.92	Although they had lost the battle. They were sure to win the…	war
0.96	A whole year of healthy eating and exercise made Jim hard to recognize. He had lost a lot of…	weight

Appendix F

Cloze probabilities for within and between-category violations.

Exemplar	Within-Category Violation	Cloze Probability for Within-Category Violations	Between-Category Violations	Cloze Probability for Between-Category Violations
ant	bee	0	mouse/squirrel	0
bear	wolf	0	cat/dog	0
bee	ant	0	mouse/squirrel	0
beer	wine	0	juice/water	0
bomb	gun	0	club/stone	0
brain	spine	0	mouth/throat	0
bus	train	0	car/truck	0
butter	milk	0	tea/coffee	0
car	truck	0	bus/train	0
carrot	potato	0	orange/lemon	0
cat	dog	0.049	bear/wolf	0
chair	couch	0	table/desk	0.024
chicken	fish	0	salt/sugar	0
city	town	0	state/country	0
club	stone	0	gun/bomb	0
coffee	tea	0.1	milk/butter	0
cotton	silk	0	silver/gold	0
couch	chair	0.02	table/desk	0
country	state	0	town/city	0
desk	table	0.1	chair/couch	0
doctor	nurse	0.02	lawyer/judge	0
dog	cat	0	bear/wolf	0
eagle	owl	0	lizard/snake	0
ears	eyes	0	feet/hands	0.04
eyes	ears	0	feet/hands	0
feet	hands	0	eyes/ears	0
field	hills	0	lake/river	0
fish	chicken	0	salt/sugar	0
flute	trombone	0.024	violin/guitar	0
gold	silver	0.02	cotton/silk	0
guitar	violin	0	flute/trumpet	0
gun	bomb	0	club/stone	0
hall	room	0	park/yard	0
hands	feet	0.02	eyes/ears	0
hill	field	0	river/lake	0
husband	wife	0	teacher/principal	0
judge	lawyer	0.024	nurse/doctor	0
juice	water	0	wine/beer	0
lake	river	0.024	field/hill	0

lawyer	judge	0	doctor/nurse	0
lemon	orange	0	carrot/potato	0
lizard	snake	0.024	owl/eagle	0
milk	butter	0	tea/coffee	0
mouse	squirrel	0	bee/ant	0
mouth	throat	0	brain/spine	0
nurse	doctor	0.24	judge/lawyer	0
orange	lemon	0	carrot/potato	0
owl	eagle	0	lizard/snake	0
park	yard	0	room/hall	0
potato	carrot	0	orange/lemon	0
principal	teacher	0.15	wife/husband	0
rain	snow	0	summer/winter	0
river	lake	0.02	hill/field	0
room	hall	0	yard/park	0
salt	sugar	0	chicken/beef	0
silk	cotton	0	silver/gold	0
silver	gold	0.02	cotton/silk	0
snake	lizard	0	owl/eagle	0
snow	rain	0	winter/summer	0
spine	brain	0	mouth/throat	0
squirrel	mouse	0	bee/ant	0
state	country	0	town/city	0
stone	club	0	gun/bomb	0
sugar	salt	0	chicken/beef	0
summer	winter	0	day/night	0
table	desk	0	chair/couch	0
tea	coffee	0.08	milk/butter	0
teacher	principal	0	husband/wife	0
throat	mouth	0	brain/spine	0
town	city	0.041	state/country	0
train	bus	0	car/truck	0.041
truck	car	0.098	bus/train	0
trumpet	flute	0	guitar/violin	0
violins	guitars	0	trumpet/flute	0
water	juice	0.024	wine/beer	0
wife	husband	0	principal/teacher	0
wine	beer	0	juice/water	0
winter	summer	0	night/day	0.02
wolf	bear	0	cat/dog	0
yard	park	0	hall/room	0