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Working memory influences on cross-language activation during bilingual lexical
disambiguation

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(Manuscript submitted for publication to *Bilingualism: Language and Cognition*)

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Abstract

This study investigated the role of verbal working memory on bilingual lexical disambiguation. Spanish-English bilinguals with low and high digit span read sentences in their second language ending in a cognate homonym (novel), noncognate homonym (fast), cognate (piano) or non-cognate (pencil). The dominant meanings of cognate homonyms were shared across languages while subordinate meanings were unique to the second language. Participants decided whether follow-up targets were related in meaning to the sentence. On critical trials sentences biased the subordinate meaning of the homonym and targets were related to the dominant meaning (novel – BOOK; fast – SPEED), forcing rejection of dominant meanings shared across the two languages. Performance patterns for both groups reflected cross-language activation of cognate meanings. The nature of these effects was facilitative for high-span participants whereas they were inhibitory in nature for low-span participants. Results are discussed in terms of theories of bilingual working memory and lexical disambiguation.

Working memory is a fundamental process in text comprehension because readers must keep available previous information while incorporating new information as they read for comprehension. Daneman and Carpenter (1980) investigated whether individual differences in working memory capacity related to individual differences in reading comprehension using a reading span task. In this task, participants read aloud sets of sentences that varied in size and were required to recall the last word of each sentence they read. They found high, positive correlations between their performance on the reading span task and three different measures of reading comprehension. Individuals with high working memory span scored higher on fact questions, on pronoun reference questions and also on the verbal SAT.

The influence of working memory on language comprehension has been studied with monolinguals with a variety of reading skills. For example, Daneman and Carpenter (1983) found that participants with high span were better at coping with garden path sentences, in which readers are led into an incorrect interpretation of the sentence and must re-analyze the sentence structure to find the correct interpretation [e.g., *The horse raced past the barn fell; The horse (that was raced past the barn) fell*]. Participants with high span were also better at drawing inferences from text. Working memory has also been found to positively correlate with the ability to understand objective-relative sentences (e.g. “The reporter that the senator attacked admitted the error”) (King and Just, 1991).

Lexical disambiguation: The influence of individual differences in working memory

Researchers have also investigated the role of individual differences in working memory and general reading skill on the processing of lexical ambiguity. According to the structure-building framework (e.g., Gernsbacher, 1990, 1996, 1997; Gernsbacher & Faust, 1991;

Gernsbacher, Varner & Faust, 1990) differences in reading skill are at least partially attributable to readers' ability to activate the multiple meanings of ambiguous words and later suppress the contextually-irrelevant ones. For example, in the sentence "He dug with the **spade**," less skilled readers have greater difficulty in suppressing the non-target meaning (e.g., "ace") than more skilled readers.

Miyake, Just and Carpenter (1994), proposed that readers with high span are able to maintain both interpretations of a homograph readily available, whereas readers with low span cannot do it so easily. They presented participants with sentences in which a homograph was preceded by neutral contexts and followed by a disambiguation cue later in the sentence (e.g. "Since Ken really liked the *boxer*, he took a bus to the nearest *pet store* to buy the animal). When the homograph had one highly frequent meaning, participants with high span showed little effect of ambiguity on encountering the disambiguation cue, irrespective of which meaning of the homograph (dominant or subordinate) turned out to be correct. Participants with low span, on the other hand, showed a large ambiguity effect when the disambiguation cue was in favor of the subordinate meaning.

In an event related potential (ERP) study, Gunter, Wagner and Friederici (2003) presented German-speaking participants characterized as having high or low working memory span, with sentences containing a homonym. In all sentences, the homonym was followed three words later by a nominal disambiguation cue and a final disambiguation using a verb [e.g., *Der Ton wurde vom Sa`nger gesungen, als...(The tone was by the singer sung, when...)*]. The ERP data revealed that for participants with low span the cueing towards the dominant or the subordinate meaning elicited equivalently large brain electrical activity suggesting that both meanings were active in working memory. For participants with high span, the dominant

disambiguation cue elicited smaller brain electrical activity than the subordinate disambiguation cue, indicating that for these subjects the dominant meaning was more active. Gunter et al. (2003) suggested this was evidence that supported inhibition as the underlying cognitive mechanism for participants with high span, because they were able to suppress the irrelevant meaning at the disambiguation point.

Consistent with these findings, Gadsby, Arnott and Copland (2008) also found evidence for an inhibition mechanism underlying working memory constraint during lexical ambiguity resolution on a primed lexical decision task. Specifically, participants with high span exhibited a pattern of priming for congruent conditions and a lack of positive priming for incongruent conditions. In contrast, participants with low span showed priming for both congruent and incongruent conditions, but only for conditions in which the context was related to the dominant meaning of the homograph. Gadsby et al. (2008) suggested that individuals with low working memory capacity have difficulty inhibiting inappropriate homograph meanings and proposed that these difficulties may vary as a function of context-meaning dominance.

The research reviewed so far addresses only monolingual studies. Working memory capacity is likely to be a key factor for bilingual lexical disambiguation because bilinguals often have less than native-like proficiency in one of their languages and the ambiguity can extend to both languages.

Lexical disambiguation: The influence of meaning activation

According to the re-ordered access model (Duffy, Morris, & Rayner, 1988), lexical disambiguation is also affected by the relative frequency of the meanings of an ambiguous word and the surrounding sentence context. The major assumptions of this model have been supported

by several studies (Kambe, Rayner and Duffy, 2001; Sereno, Rayner and Posner, 1998; Sereno, Brewer and O'Donnell, 2003) The general methodology employed across these studies has been to monitor readers' eye movements as they read sentences containing lexically ambiguous words which were either non-polarized (two meanings equally frequent) (e.g., fast) or polarized words (one meaning more dominant than the other) (e.g., fan).

When polarized words are preceded by a neutral context (disambiguating context after the ambiguous words), processing time is similar to that of control, (unambiguous) words. This suggests that the more dominant meaning of the word is activated early in processing, not allowing the subordinate meaning to compete for selection. However, when these same words are preceded by a disambiguating sentence that biases the subordinate meaning of the word, longer gaze durations are observed, compared to controls. This suggests that the provided disambiguating context allows for the subordinate meaning to become activated earlier and to compete for selection with the dominant meaning. This effect is what has been called the subordinate bias effect.

The re-ordered access model is based on monolingual reading and in its current form it does not account for cross-language lexical dynamics. As described in more detail below, bilingual lexical access is language non-selective. Thus, this is yet another factor that needs to be considered when accounting for bilingual lexical disambiguation.

Bilingual lexical access: evidence of non-selectivity

The past ten years of cognitive psycholinguistic research has shown that bilingual lexical access is non-selective. In other words, despite a bilingual's intentions to perform language tasks in only one language, both languages are activated in parallel and thus influence language

processing. (e.g., Arêas da Luz Fontes & Schwartz, submitted; De Bruin, Dijkstra, Chwilla & Schriefers, 2001; Dijkstra, De Bruin, Schriefers & Brinke, 2000; Dijkstra, Timmermans & Brinke, 2000; Dijkstra & Van Hell, 2003; Gollan, Forster, & Frost, 1997; Jared & Kroll, 2001; Van Heuven, Dijkstra, Grainger & Schriefers, 2001; Schwartz, Kroll, & Diaz, 2008). For example, cognate facilitation effects have been consistently observed across a diversity of tasks and paradigms (Dijkstra, Grainger & Van Heuven, 1999; Gollan et al., 1997; Kroll & Stewart, 1994).

Non-selectivity has been shown to persist even in sentence processing tasks (Duyck, Van Assche, Drieghe & Hartsuiker; Elston-Güttler & Friederici, 2005; Schwartz & Kroll, 2006; Van Hell & De Groot, 2008; Libben and Titone 2009). These studies taken together have shown one consistent finding: the simple presence of a language cue provided by a sentence context is not enough to eliminate non-selective, cross-language activation. For example, Van Hell and De Groot (2008), Schwartz and Kroll (2006), Duyck et al. (2007) and Libben and Titone (2009) observed cognate facilitation when these cognate words were embedded in sentence contexts that provided little semantic information (i.e. low-constraint sentence). Using eye-tracking methodology, Libben and Titone (2009) also found cognate facilitation in high constraint sentences, however this was only evident in measures tapping into earlier stages of lexical access (e.g., first fixation duration).

Non-selectivity can also be constrained by the surrounding, experimental language context. German-English bilinguals performed a second language lexical decision in which sentences ended in interlingual homographs (e.g. bald) and followed by a target that reflected the German meaning of the homograph (e.g. soon). Half of the participants saw a film in the non-target language (German) prior to completing the task (Elston-Guttler, Gunter & Kotz, 2005).

Priming effects were only observed for participants that saw the German version of the film (the non-target first language), and only during the first half of the experiment. The authors suggested that during the first half of the experiment there still existed some residual information from first language as participants' cognitive processing of interlingual homographs attempted to zoom into the new second language setting. However, with time and additional second language input, participants' processing of interlingual homographs was able to behave selectively, eliminating first language influence.

The studies reviewed above suggest that the bilingual lexicon remains permeable to cross-language interactions, however the presence of a meaningful context can shorten the duration of this interactivity. Thus, in order to examine bilingual lexical disambiguation one must consider the existence of multiple languages, and their potential interactions. For example, the word "novel" in English has two possible meanings: a book or something new. However, the word novel is also a cognate with Spanish (e.g. "novela"). Therefore, when a Spanish-English bilingual encounters the word "novel", all of its meanings in English are activated, as well as the representation of its Spanish cognate. This concurrent activation creates lexical ambiguities within languages as well as across languages. What follows is a review of some recent studies looking at bilingual lexical disambiguation.

Bilingual lexical disambiguation

Elston-Güttler, Paulmann & Kotz (2005) examined whether the competitive dynamics between the multiple meanings of first language homonyms would influence processing in an exclusively second language task. They created prime-target pairs by translating German homonyms (*Kiefer* can be translated as either "pine" or "jaw"). One of the homonym translations

was presented as the last word of the sentence and the other was presented as a follow-up lexical decision prime word followed by a target word. Low-proficiency German-English bilinguals showed strong overall interference from the first language in the ERP and reaction time data. High-proficiency bilinguals, on the other hand, showed no interference from the first language on either measure. The authors concluded that the ERP and reaction time effects observed for low-proficiency bilinguals in sentence context make a strong case for a highly integrated lexicon linked at the word form level and a fundamentally non-selective word-recognition system.

Schwartz, Yeh & Shaw (2008) used a similar paradigm to examine the influence of cross-language activation on bilingual lexical disambiguation. They presented highly proficient bilinguals with sentences that biased the subordinate meaning of an English homonym. These homonyms were either noncognates (e.g., fast/rápido) or cognates (novel/novela) with Spanish, and were always presented as the last word of the sentence (e.g., “She is a creative thinker and her ideas are often novel.”). Sentences were followed by target words that, on test trials, were related to the dominant, contextually irrelevant meaning of the homonym (e.g., BOOK). Participants were asked to decide if the follow-up target words were related to the overall meaning of the sentence they had just read (thus requiring a “no” response).

Participants exhibited longer reaction times and error rates when the last word of the sentence was a homonym and the follow-up target word was related to its dominant meaning (e.g., fast – SPEED; novel – BOOK). More interestingly, the relative cost of this ambiguity effect was greater when the homonym was also a cognate with Spanish (e.g., novel – BOOK). This suggests that the contextually irrelevant, dominant meaning received co-activation from both of the bilinguals’ languages thus producing more interference during the disambiguation process.

In summary, research on bilingual lexical disambiguation demonstrates that access to the different meanings of a homonym is influenced by cross-language activation and that selection of a particular meaning involves inhibitory mechanisms. The extent to which working memory capacity could constrain this co-activation of languages or whether it could affect the direction (facilitation or interference) of the cross-language activation effect has not yet been studied. The goal of the present study was to examine whether individual differences in verbal working memory modulate the magnitude and direction of these influences.

The present study

The goal of the present study was to investigate the role of working memory capacity in cross-language activation during the process of lexical disambiguation. Therefore, in the present study we addressed this question and hypothesized that working memory capacity could influence the direction of cross-language activation effects. We investigated this question using the same semantic verification task as Schwartz et al. (2008) in which participants had to reject irrelevant meanings of English homonyms (e.g., arm) that on half of the trials were cognates with Spanish (e.g., arma). We hypothesized that only participants with high span would be able to take advantage of the earlier, stronger activation of cognates in working memory and show patterns of cognate facilitation. Participants with low span, on the contrary, would show patterns of cognate interference because they would not be able to handle cross-language activation as efficiently. In addition, we expected to replicate results from Gunter et al. (2003) in which participants with high span were more efficient in inhibiting the inappropriate meaning of homonyms than participants with low span.

Methods

Participants

Two hundred and thirty five undergraduate students from the University of Texas at El Paso were recruited from Introduction to Psychology and upper level Psychology courses. Only participants whose responses on the Language History Questionnaire (LHQ) reflected high levels of proficiency in both English and Spanish were included in the analyses (see the Results section for more details regarding these criteria). This led to an exclusion of 69 participants, a rate of 29.4%. In addition, only participants whose scores on the Spanish digit span task reflected high or low working memory capacity were included in the analyses. Participants at the intermediate level (N=91) were also excluded, a rate of 38.7%. Therefore, the final group of Spanish-English bilingual students consisted of 75 participants.

Tasks and Materials

Semantic verification task. The first task participants completed in the study was the Semantic Verification Task. In this task, participants were presented with a sentence frame with the last word missing (e.g., *He is an original thinker and all of his ideas are exciting and _____*). Participants then pressed the middle key of a response box when they were ready to read the last word of that sentence, the prime word (e.g. *novel*), which was followed by the target word (e.g. *NEW*) after a stimulus asynchrony onset (SOA) of 1250 milliseconds (ms). Finally, participants were asked to decide whether the target word was semantically related to the overall meaning of the previously presented sentence by pressing the “yes” or “no” keys on a

response box. All prime words were presented in lowercase letters while target words were presented in uppercase letters.

Stimulus words. The same critical stimuli as Schwartz et al. (2008) were used. There were four groups of experimental English prime words, which were based on a 2 X 2 manipulation of ambiguity and cognate status with Spanish. (See Table 1 for examples). This manipulation generated the following conditions: ambiguous-cognates, ambiguous-noncognates, unambiguous-cognates and unambiguous-noncognates. Prime words were matched for frequency and length: ambiguous cognate primes were matched with ambiguous noncognate primes, while unambiguous cognates were matched with unambiguous noncognates.

Insert Table 1 around here

Stimulus sentences. Materials consisted of 160 sentences. Half of these sentences were experimental trials that to be correctly responded to, required a “no” response. The other half was filler trials and required a “yes” response. Each sentence frame was presented on the computer screen with the last word missing. The word that was missing, the prime word, was from one of four possible conditions: ambiguous-cognate, ambiguous-noncognate, unambiguous-cognate and unambiguous-noncognate or a filler word for “yes” trials (see Table 2 for examples). The prime word was always the last word of the sentence followed by the target word. In the ambiguous, experimental trials, the meaning of the sentence always biased the subordinate meaning of the ambiguous word (e.g., novel – NEW). In the case of the unambiguous, control trials, the target was a word not related to the meaning of the sentence. In both cases, the correct answer was “no.” For the filler trials, the target word was related to the meaning of the sentence

and required a “yes” response. Experimental and filler sentences were matched on length. Furthermore, to ensure that the presence of an ambiguous word would not cue a “no” response filler trials also included ambiguous prime words.

Insert Table 2 around here

Digit span task. The second task participants completed was the Digit Span task. In the Digit Span task, participants heard a sequence of numbers in a series that increased from three to eight digits and were asked to recall these numbers in order after each trial. There were two trials of each length of digits and after participants heard each of the trials, they were given as much time as they needed to recall the numbers and to type them in the space provided on the computer screen.

Participants completed two versions of the Digit Span task, one in English and one in Spanish. The only difference between the two was that in the Spanish version the numbers were said in Spanish. However, instructions to the task were in English.

Procedure

When participants arrived at the lab, they were greeted in English and asked to sign an informed consent form. After agreeing to participate, the participant was taken to an individual testing room where he or she was seated in front of a computer.

The first task was the Semantic Verification task. Instructions were presented on the computer screen as well as orally by the experimenter. The participant had a chance to complete 20 practice trials with feedback from the experimenter. Once the participant was ready to continue he or she pressed the

middle key on the response box and a fixation point appeared on the middle of the screen. The task was self-paced, so whenever the participant was ready he or she could press the middle key on the response box to see the next sentence. The sentence frame was then presented on the screen. The sentence always had the last word missing. To see the last word, participants pressed the response box when they were ready. The last word of the sentence (prime word) was then presented for 250 milliseconds (ms), followed by a blank screen for 1000ms, which was then followed by a target word presented in all capital letters. The participant was then required to make a decision as to whether that target word was related to the meaning of the sentence previously read. “Yes” responses were made with a right-hand key press and “no” responses with a left-hand key press on a response box. After the response was made another fixation point appeared on the screen and the participant had to press the space bar to see the next sentence and so on. This continued for 160 trials until the task was complete.

After finishing the Semantic Verification task, participants completed the English version of the Digit Span task. Again, instructions were presented on a computer screen as well as orally. Participants were instructed to listen to all digits on each trial, to remember them in order and then type them on the space provided after each trial. The first trial consisted of three digits and it increased consistently by one digit until it reached nine digits. Digits ranged from one to nine and digits within trials were randomized. Consecutive repetition of digits was allowed, such that participants could hear a trial such as “3477.” After data was collected, digit span trials that included consecutive repeated digits were dropped from analysis. This led to the exclusion of less than 1% of valid trials.

The next task was the Spanish version of the Digit Span task. Instructions to this task were the same as the English version. Finally, participants completed the language history questionnaire. This questionnaire assessed their language background and abilities in English and Spanish. Participants self-

reported their speaking, reading, comprehension and speech skills in both English and Spanish. They also reported how often and the contexts in which they speak each of the languages.

At the end of the experiment, participants received a debriefing form that explained more about the study. They were also given an opportunity to ask questions about the study.

Data analysis procedures

Language history questionnaire data. Data from the LHQ are summarized in Table 3 for the high verbal working memory participants and in Table 4 for the participants with low verbal working memory. Participants whose self-assessed proficiency ratings in both languages were at least a five were classified as bilingual. Furthermore, any participant whose rating in Spanish was slightly below five (3-4) and who reported learning Spanish before the age of five and using Spanish on a daily basis was also classified as a bilingual and included in the analyses. This was due to the fact that participants were residing in a highly –bilingual community and tended to rate their Spanish skills relatively low.

Insert Tables 3 and 4 around here

Digit span data. We calculated a digit span score for each participant by counting the number of total consecutive digits recalled without error. For example, if a participant recalled up to five digits and incorrectly recalled the following sixth digit, his or her span was identified as five. In addition, participants received half a point for each trial recalled after the first error.

For example, if the participant missed both six digits, but was able to recall one of the seven-digit trials, he or she received half a point.

Participants were divided into two different span groups based on their performance on the Spanish digit span task. Because an individual's average working memory span has been shown to be seven, plus or minus two digits, we classified participants who were able to recall five or less digits as participants with low span ($n=24$), while participants who were able to recall seven or more items were classified as participants with high span ($n=51$). Performance on the Spanish digit span task was used in the analyses because they provided a larger range of working memory span scores (very few participants had an English digit span of five or less).

Data trimming procedures for semantic verification data. Mean reaction time (RT) for each participant for correct trials was calculated. Any participant who had an error rate percentage greater than 80% on either of the two critical trials (ambiguous cognate and ambiguous non-cognate) was excluded from further analyses ($n=3$). In addition, participants who had an error rate percentage greater than 30% on the control trials (unambiguous-cognate and unambiguous non-cognate) were also excluded ($n=2$). These conditions led to an exclusion of 6.6% of the participants (5/75). Therefore, data from 70 participants was analyzed in the following analyses.

Results

Test of homogeneity

We conducted a test of homogeneity on both the reaction time and accuracy data. The test of homogeneity for reaction times was not significant [$F(10, 9178.5)=1.40, p=.172$] suggesting

that the error variances across groups was equal. For the accuracy data, however, the test of homogeneity was significant [$F(10, 9178.5)=1.97, p=.03$], suggesting that error variances across groups were unequal. Therefore, we submitted the accuracy data to an arcsine transformation. The accuracy data presented below is the arcsine-transformed data, however, for ease of interpretation we will refer to it as percentages.

Comparison of language background data

Independent sample t-tests were conducted between participants with high and low span for each of the language background variables to see whether the groups differed in their language proficiency skills. None of the language background variables (age of acquisition, frequency and mean self-ratings) were different between the groups, suggesting that the groups were equivalent in their age of acquisition of each language, frequency of use of each language and language abilities in both English and Spanish. All p values exceeded .05.

Comparison of span groups

For each span group, we conducted paired t-tests to assess whether there was a difference in participants' English language skills and Spanish language skills.

Participants with high span. Participants with high-span reported learning Spanish at an earlier age ($M=2.9$ years) than English ($M=5.6$ years), $t(45) = 3.72, p<.000$. Nevertheless, their average proficiency self-ratings (averaged across reading, writing, speaking and listening comprehension) were higher in English ($M=9.3$) than Spanish ($M=7.7$), $t(46) = 4.77, p<.000$, and they reported using English ($M=7.9$) more frequently than Spanish ($M=7.6$), $t(44) = 2.43, p=.02$, suggesting they had become more dominant in English.

Participants with low-span. Participants with low-span reported learning Spanish (M=4.0 years) and English (M=5.2 years) at around the same age $t(21) = .94, p=.36$. They also reported equally frequent use of English (M= 7.8) and Spanish (M=7.3), $t(22) = 1.44, p=.16$. Similar to participants with high span, average proficiency self-ratings for participants with low-span were higher in English (M=9.0) than Spanish (M=7.6), $t(22) = 2.82, p=.01$.

Semantic verification data

Reaction time data. We submitted mean decision latencies on correct “no” trials to a 2 (digit span status) X 2 (ambiguity status) X 2 (cognate status) mixed ANOVA. Both ambiguity and cognate status were manipulated within subjects, while digit span status was used as a between-subjects variable.

The main effect of ambiguity was not significant ($F(1,68)=1.44, MSE=54987.3, p=.23, d^2=.021$), indicating that participants’ responded equally fast to targets preceded by an ambiguous prime (M=1376) as to targets preceded by an unambiguous prime (M=1340.2). The main effect of cognate status was significant, ($F(1,68)=6.57, MSE=17740, p=.01, d^2=.088$), reflecting participants’ faster reaction times on targets preceded by a cognate prime (M=1336.4) than on targets preceded by a non-cognate prime (M=1379.8).

There was significant interaction between ambiguity status and digit span status ($F(1,68) = 4.51, MS=54987.3, p=.04, d^2=.062$). Follow-up paired t-tests revealed that participants with low span were slower to respond to targets preceded by an ambiguous prime than to targets preceded by an unambiguous prime, $t(22)=2.30, p=.03$. This difference was not significant for participants with high span, $t(46)= -.766, p=.45$, (see Figures 1 and 2). This finding suggests that participants with low span had not yet resolved the competition between the homonyms’

meanings at the time of the target presentation while those with high span had done so. The interaction between ambiguity and cognate status ($p=.09$), cognate status and digit span status ($p=.27$), as well as the three-way interaction ($p=.90$) were not significant.

Insert Figures 1 and 2 around here

Accuracy data. We submitted mean percent error rates across “no” trials to a 2 (digit span status) X 2 (ambiguity status) X 2 (cognate status) mixed ANOVA. Again, digit span status was the between-subjects variable and ambiguity and cognate status were the within-subjects variables.

The main effect of ambiguity was significant ($F(1,68)=83.43$, $MSE=.031$, $p<.000$, $d^2=.55$), revealing participants’ higher error rates on targets preceded by an ambiguous prime ($M=.40$) than on targets preceded by an unambiguous prime ($M=.20$). The main effect of cognate status was not significant ($F(1,68)=1.81$, $MSE=.018$, $p=.18$, $d^2=.026$), reflecting the fact that participants had similar error rates on targets preceded by a cognate prime ($M=.31$) and on targets preceded by a non-cognate prime ($M=.29$).

The interaction between ambiguity and cognate status was significant ($F(1,68)=14.38$, $MSE=.014$, $p<.000$, $d^2=.175$). This interaction reflected the fact that when targets were preceded by an unambiguous prime there was a cognate facilitation effect, whereas when targets were preceded by an ambiguous prime there was a cognate interference effect. This finding is a replication of Schwartz et al (2008).

The interaction between cognate status and digit span status was also significant ($F(1,68)=5.5$, $MS=.018$, $p=.02$, $d^2=.075$). Examination of Figures 3 and 4 reveals that for participants with low verbal working memory span the cost associated with ambiguity was markedly greater for cognates than for non-cognates $t(22) = 3.28$, $p = .003$. This was not the case for the participants with high span, $t(46) = 1.69$, $p = .10$. Further examination of Figures 3 and 4 reveals that there was a cognate facilitation effects for the unambiguous conditions for the participants with high- span only, $t(46) = -2.60$, $p = .01$. The interaction between ambiguity status and digit span status ($p = .180$), as well as the three-way interaction ($p=.995$) were not significant.

This pattern of results demonstrates that performance for both groups was influenced by cross-language lexical activation. Interestingly these effects were largely inhibitory in nature for participants with low span but facilitative for participants with high span.

Insert Figures 2 and 3 around here

Discussion

The major findings of the present study suggest that verbal working memory span influences the extent to which performance during lexical disambiguation is marked by facilitative versus inhibitory effects of cross-language activation. More specifically, for participants with low span, performance on the semantic verification task was characterized mainly by inhibitory effects. For example, these participants had much higher error rates on ambiguous cognate trials than on ambiguous non-cognate trials. Participants with high span did not show this cost associated with cognate status.

One possible explanation is that the activation strength of cognates is greater than for noncognates because cognates have overlapping orthographic and semantic representations across languages. If cognates have greater activation than noncognates, then rejecting them requires more working memory resources. Thus, participants who have fewer resources available and thus have low working memory span, would have more difficulty in rejecting cognates than participants with high span, who have more resources available.

Conversely, the performance of participants with high span was less marked by inhibition, and even showed some facilitative effects for the unambiguous trials. Specifically, these participants showed cognate facilitation effects in both RT's and error rates for the unambiguous trials. Thus, it seems that bilinguals with high verbal working memory are at a double advantage: Not only are they better able to inhibit competing semantic representations, even when these are co-activated across languages (both "novel" and "novela" feed forward activation to the "BOOK" meaning); they are also better able to reap the benefits when the lexical representations converge onto a single semantic representation across languages.

These findings converge with the major assumptions of the Structure Building Framework described in the introduction. According to the Structure Building Framework (e.g., Gernsbacher, 1990, 1996, 1997; Gernsbacher & Faust, 1991; Gernsbacher, et al., 1990) comprehension relies on two cognitive mechanisms: enhancement and suppression. Skilled readers are able to more readily activate lexical information (enhancement) as well as inhibit irrelevant information (suppression). In the present study bilinguals with high verbal working memory were similarly better able to activate lexical information (showing cognate facilitation) without compromising efficiency in suppression (not showing a larger ambiguity cost for cognates).

The present study also converges with and extends the Re-ordered Access Model (Duffy et al., 1994). As discussed in the introduction, this model assumes that the time-course with which homonym meanings become activated is influenced by two factors: (1) the relative frequency of the alternative meanings and (2) whether the context biases a certain meaning. This model would predict that the contextual support for subordinate meanings would not be sufficient to bypass competition from the more frequent, dominant meaning. The increased error rates for the ambiguous conditions support this claim. However, the magnitude of the cost of competition was greater for ambiguous cognates than non-cognates. This suggests that cross-language activation of the cognate translations from the non-target language increased the strength of activation of the shared, dominant meanings. This finding highlights the importance of cross-language activation as a factor in bilingual sentence processing research. Broadly speaking, it suggests that to apply monolingual models of lexical ambiguity resolution to bilinguals, we have to consider cross-language activation. A bilingual version of this model should include cross-language lexical activation as a third factor (as previously suggested by Schwartz, Yeh & Arêas da Luz Fontes, 2008).

The finding from the present study that individuals with low working memory span responded slower to ambiguous words than individuals with high working memory span replicates Miyake et al. (1994), although using a different paradigm. Contrary to our study, which used biased sentences, Miyake et al. (1994) used neutral sentences. Miyake et al. (1994) proposed an activation hypothesis to explain the absence of an ambiguity effect in the high-span group. Because the context preceding the ambiguous word was a neutral one, they suggested that participants with high span were able to activate all possible meanings and keep them available until the disambiguation region, while participants with low span had only the dominant meaning

available at that point. Therefore, when the disambiguating region cued the subordinate meaning, participants with low span showed difficulty in selecting the subordinate meaning.

In the present study, however, the sentences were designed to bias the subordinate, less frequent meaning of the ambiguous word. In this case, the context preceding the ambiguous word allowed the subordinate meaning to receive some level of activation and compete with the dominant meaning. Therefore, because of our task demands, which required participants to reject a target related to the dominant meaning, it seems that an inhibition hypothesis would better explain our findings. It may be that in the present study, participants with high span did not show an ambiguity effect because they were better able to select the correct meaning early and inhibit the dominant meaning more efficiently than participants with low span. Participants with high span may inhibit dominant meanings more efficiently because they have more processing resources available during sentence comprehension. Participants with low span, on the other hand, could not reject the target related to the dominant meaning because both interpretations were still available and competing for activation.

If that is the case, then our findings are also consistent with Gunter et al. (2003), who found that inhibition is more likely to be responsible for lexical ambiguity resolution effects. In a series of three experiments, Gunter et al. (2003) found that both high and low span participants read an ambiguous word and activated both meanings, although participants with high span may have done so to a greater extent. The difference between the groups occurred at the point of disambiguation. Gunter et al. (2003) proposed that when they arrived at the disambiguation cue, participants with high span had suppressed the subordinate meaning in working memory because the dominant disambiguation cue elicited smaller brain electrical activity than the subordinate disambiguation cue, indicating that for these subjects the dominant meaning was more active. On

the other hand, participants with low span had both meanings present in working memory when they arrived at the disambiguation cue, slowing their response.

In addition, in Gunter et al. (2003) the groups differed in their ability to switch between the possible correct interpretations of the ambiguous word. If the disambiguation cue indicated that a subordinate meaning was probably correct, participants with high span could easily switch to the subordinate meaning. Then, if the sentence continued, without any more evidence that the subordinate meaning was correct, participants with high span switched back to the dominant meaning and later ran into trouble if the subordinate meaning turned out to be correct. Participants with low span, in contrary, could switch between meanings only if enough time was allowed. However, if a fast response was required, they had problems suppressing the dominant meaning.

This explanation proposed by Gunter et al. (2003) could be applied to the findings from the present study. Although sentences in our study biased the subordinate meaning of the ambiguous word, thus allowing for early selection of the subordinate meaning, our stimuli was designed to “trick” participants into switching which meaning had to be correctly selected by presenting a target related to the dominant meaning. In our study, participants with low span showed the same pattern as in Gunter et al. (2003), in which they had trouble rejecting the target related to the dominant meaning, even when context allowed for early selection of the subordinate meaning. Participants with high span, on the other hand, were able to make the switch by quickly rejecting the dominant meaning. This may be because they had already suppressed the dominant meaning since the preceding context allowed for selection of the subordinate meaning.

Applications

Findings from this study highlight the impact that lexical ambiguity has on the reading process, particularly for bilingual readers. When there is a lack of a one-to-one mapping between form and meaning processing efficiency is compromised. This effect is even greater when the mappings are cross-linguistic. Working memory is a fairly stable characteristic and not easily modified by instruction. Thus, it is critical that bilingual readers engage in activities that build underlying lexical representations. A highly detailed, accurate and well-entrenched lexical representation minimizes the processing costs associated with ambiguity and processing in a weaker language. Teachers can do this at both an implicit and explicit level. Lexical knowledge is acquired implicitly through rich and varied reading experiences. Teachers can also help students navigate the ambiguity of the lexical code explicitly. One way this can be done is by raising students' meta-cognitive awareness of the existence of cognates and homographs. Students can be asked to keep a list of cognates and homographs that they encounter during their readings in the second language. Making students aware of similarities and differences across their languages may increase their familiarity with the second language.

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Table 1

Lexical characteristics of prime and target words

| | Condition | | | |
|------------------------|------------------|------------|--------------------|---------------|
| | Ambiguous Primes | | Unambiguous Primes | |
| | Cognate | Noncognate | Cognate | Noncognate |
| Example Pair | novel- BOOK | drag- PULL | poet- BUILD | happy- BEAUTY |
| Mean Prime | 113.8 | 95.9 | 70.2 | 101.1 |
| Frequency ¹ | | | | |
| Mean Prime | 5.1 | 5.0 | 5.9 | 6.0 |
| Length ² | | | | |
| Mean Target | 98.0 | 115.5 | 97.1 | 115.1 |
| Frequency ¹ | | | | |
| Mean Target | 5.5 | 5.0 | 5.0 | 5.1 |
| Length ² | | | | |

¹. Celex². Number of letters

Table 2. Example sentences prime and target words across the four conditions

| Prime condition | Sentences | Prime | Target |
|-------------------------|---|-------|--------|
| Ambiguous cognate | He is an original thinker and all of his ideas are | novel | BOOK |
| Ambiguous non-cognate | Before tossing the cigarette she took one more | drag | PULL |
| Unambiguous cognate | Though he sometimes wrote prose, he was also a | poet | BUILD |
| Unambiguous non-cognate | She was tired of feeling depressed and made an effort to feel | happy | WOOD |

Table 3. Language experience, digit spans and self-assessed proficiency ratings of the participants with high span.

| | English | Spanish |
|--------------------|---|------------|
| Digit Span | 6.9 | 7.3 |
| Age of Acquisition | 5.4 | 2.9 |
| | <u>Self- assessed ratings¹</u> | |
| Reading | 9.3 | 7.6 |
| Writing | 9.1 | 6.7 |
| Speaking | 9.3 | 7.9 |
| Listening | 9.5 | 8.4 |
| Mean rating | 9.3 | 7.7 |

¹Self-assessed ratings based on a scale 1-10.

Table 4. Language experience, digit spans and self-assessed proficiency ratings of the participants with low span. Self-assessed ratings based on a scale 1-10.

| | English | Spanish |
|--------------------|---|------------|
| Digit Span | 6.1 | 4.8 |
| Age of Acquisition | 5.2 | 3.9 |
| | <u>Self- assessed ratings¹</u> | |
| Reading | 9.0 | 7.7 |
| Writing | 8.7 | 7.0 |
| Speaking | 9.2 | 7.6 |
| Listening | 9.3 | 8.2 |
| Mean rating | 9.1 | 7.7 |

¹Self-assessed ratings based on a scale 1-10.

Figure Captions

Figure 1: Mean decision latencies for participants with low verbal working memory across the four critical conditions

Figure 2: Mean decision latencies for participants with high verbal working memory across the four critical conditions

Figure 3: Mean percent error rates for participants with low verbal working memory across the four critical conditions

Figure 4: Mean percent error rates for participants with high verbal working memory across the four critical conditions







