FASTER ISN'T NECESSARILY BETTER:

THE ROLE OF INDIVIDUAL DIFFERENCES IN PROCESSING WORDS WITH MULTIPLE TRANSLATIONS

by

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Abstract

Words that can translate several ways into another language have only recently been examined in studies of bilingualism. The present study examined how individual differences in working memory span and interference affect the processing of such words during a translation task. 20 English-Spanish bilinguals performed a Stroop task and an operation word span task to determine their interference abilities and working memory spans, respectively. They then translated from English to Spanish and Spanish to English 239 words that varied in number of translations and concreteness. Bilinguals with lower interference and lower working memory spans were predicted to have the fastest response times for words with multiple translations, due to the ability to better suppress irrelevant information as well as limited capacity to hold several competing translations of a word in memory at once. Individuals with higher interference and higher working memory spans were predicted to be able to access and hold in memory all possible meanings of the word at once, yielding slower response times. The results demonstrated that interference and working memory span did predict response times in the translation task in accordance with the hypotheses, and can have significant impact on several aspects of translation.

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I would like to acknowledge my advisor Natasha Tokowicz (University of Pittsburgh) and Erica Michael (Carnegie Mellon University) for beginning this study and allowing me to continue it for the purpose of this project. I would also like to thank my defense committee Erik Reichle (University of Pittsburgh), Tessa Warren (University of Pittsburgh), and Gretchen Sunderman (Florida State University), as well as everyone in the PLUM Lab group at the University of Pittsburgh (particularly Rhonda McClain and Tamar Degani) for their contributions and support.

INTRODUCTION

Bilingualism is an increasingly more prevalent characteristic among people today. There are some theories that explain how bilinguals generally process second language (L2) information, but there are still a vast number of differences among individual bilinguals (Doughty & Long, 2003; Michael & Gollan, 2005) and at different stages of L2 learning (e.g., Tokowicz & Kroll, 2001). Some people seem to easily acquire a second language quickly, and yet others may study for years and never achieve proficiency. Understanding the underlying cognitive mechanisms of language learning and processing could facilitate more effective learning and intercultural communication.

The purpose of the present study was to gain further understanding into individual differences and how they affect translation, particularly when words have multiple translations. Translation ambiguity has been shown to affect translation and language representation (Prior, MacWhinney, & Kroll, in press; Tokowicz & Kroll, in press; Tokowicz, Prior, & Kroll, 2007). Words with multiple and/or ambiguous translations are prevalent in English and Spanish as a cross-language pair. In this study, we sought to understand how the effects of ambiguity differ in bilinguals with varying cognitive abilities.

One individual difference characteristic that affects the learning and processing of an L2 is working memory span[1] (Michael & Gollan, 2005). Working memory, the ability to retain and simultaneously process many pieces of information in memory at once is related to language processing (Tokowicz, Michael, & Kroll, 2004). Individuals with higher or lower working memory spans should be differentially able to translate words into another language, even going beyond knowledge differences. During a translation task, the presentation of a word in one language causes the person to retrieve the meaning associated with that word, and then retrieve the other language word attached to that meaning (De Groot, 1992; Kroll & Stewart, 1994). Working memory allows the bilingual to activate the meaning of the word in both languages.

Another important and related individual difference characteristic is interference, which is a person's susceptibility to being distracted by irrelevant information. We gauged bilinguals' susceptibility to interference by using a Stroop task (1935) which is commonly used to measure inhibition, the ability to suppress irrelevant information when trying to focus solely on information relevant for a particular task[2]. During a Stroop task, an individual is presented with names of colors, either written in the same color of the ink as the word (congruent) or written in a different color (noncongruent). The task is to say the color of the ink, not what the word actually says. For example, if the word "blue" is written in red ink, the correct response to that trial would be "red." This task measures how much interference is caused by the irrelevant information (the lexical form of the word) when the participant is only trying to focus on the information relevant to the task (the color of the ink). Miller and Kroll (2002) found that a similar type of interference occurred in bilingual translation when participants were presented with semantically related distractor words; the meaning of the distractor word interfered with the bilinguals accessing the correct translation equivalent. It is reasonable to think that interference would occur in other aspects of language processing as well: an individual speaking in one language must actively ignore the other language and all its rules of grammar, vocabulary, and production. When this distractor information is present, the interference could come at a cost to translation production.

Words that are ambiguous or have more than one correct translation present an interesting facet of the bilingual lexical system because they are processed differently than words with a single correct translation. In a previous study conducted by Tokowicz and Kroll (in press), words with multiple translations were translated more slowly than words with single, clearly dominant translations. Moreover, words with multiple translations showed the typical concreteness effect whereas words with single translations did not. Tokowicz and Kroll also found an interaction between concreteness and number of meanings in words in monolinguals. Gernsbacher (1993) demonstrated that even within one language, interference for ambiguous words persisted more for individuals less skilled in comprehension, and that this had a cost on language processing. These studies demonstrate that ambiguous words require additional time to be processed, and that the effects of concreteness may depend on word ambiguity.

Generally, concrete words translate fairly directly from one language to another, in one or both directions of translation. For example, the word "dog" in English translates directly to "perro" in Spanish. It is easy to think of the object that the word "dog" represents, regardless of whether or not the context is available.

However, there are both abstract and concrete words that do not translate directly or could translate in multiple ways. For example, the word "glass" in English could be translated two ways: one translation is "vaso," which is a drinking instrument; the second is "vidrio," which is the material. This example illustrates a word with multiple meanings, and therefore more than one translation in this direction of translation (English to Spanish).

Another example in the other direction (Spanish to English) is the word “medida,” which could have several meanings, depending on the context. In English, this could be translated as the nouns “measure,” “measurement,” or “size.” Medida is an abstract word, having more translations and usually needing a context to understand which translation is appropriate.

One model that explains how two languages can be stored in a bilingual’s mind is the Distributed Feature Model (De Groot, 1992). The DFM posits that words are distributed throughout bilingual memory. Concrete words are more likely to share the same representational distribution across languages because they are more likely to overlap in meaning across languages. Many words, however, do not completely share meanings across languages, and would only share a subset of the conceptual representation.

An extension of the ideas proposed by the DFM could explain the concrete-word advantage found in the previous literature. Concrete words are more likely to share meanings across languages and have fewer translations than abstract words, allowing them to be translated more quickly (Tokowicz et al., 2002). Stronger representational overlappings of concrete words across languages could also allow easier retrieval of these words in general during translation production (e.g., Tokowicz & Kroll, in press).

Much of the previous research in this area has failed to consider the possible differences in translation tasks between words with one commonly accepted translation and words that could correctly translate in several ways. In preparation for one study, Finkbeiner et al. (2004) found that only 52 words out of a list of 170 were translated the same in both directions of translation by two groups of bilinguals. A large portion of words used in previous studies to examine translation times were later found to have more than one translation, making these results in previous literature unreliable because they did not consider the different processes used in translating words with multiple translations. Tokowicz et al. (2002) compiled ratings on many words used in past research and found that semantic similarity is negatively correlated with number of translations, but positively correlated with concreteness. Prior, MacWhinney, and Kroll (in press) also found that high frequency words tend to have fewer translations than low frequency words and are more likely to be given as a response in a translation task. Therefore, word ambiguity could have been responsible for some findings that were attributed to other factors.

Translations in languages can also be influenced by word meanings based on cultural values. Schwanenflugel, Blount, and Lin (1991) propose the idea that differences in word meanings exist because of cultural differences, and they are affected by the familiarity and context of the object the word represents. Malt, Sloman, and Gennari (2003) found that even common, concrete objects have different labels depending on where and how the objects are used. For more ambiguous words, culture may influence the manner in which something is communicated.

Translation can also be affected by proficiency at the individual level. Perhaps the response time difference in translation tasks in which words have more than one translation can arise from the fact that more proficient bilinguals, by virtue of having a higher proficiency, have a larger L2 vocabulary base than less proficient L2 learners.

This would give those individuals a larger choice of words to choose from in a translation task because there are more known words available (e.g., Tokowicz, 2005).

The Revised Hierarchical Model (RHM) is another relevant model of bilingual memory representation (Kroll & Stewart, 1994). The RHM proposes that L1 and L2 are connected by a two-way lexical link, and both L1 and L2 have their own links directly to concepts (see Figure 1). During early stages of L2 learning, the links between L1 and L2 are entirely lexical. Because L1 is the individual's native language, the L1 link to concepts formed first and is much stronger than the L2 link to concepts. The conceptual link for L2 develops with increased proficiency. This theory is supported by several important findings in the field, such as the fact that L1-to-L2 translation is performed more slowly than L2-to-L1 translation, as well as higher latencies in translations for which the conceptual links are ambiguous.

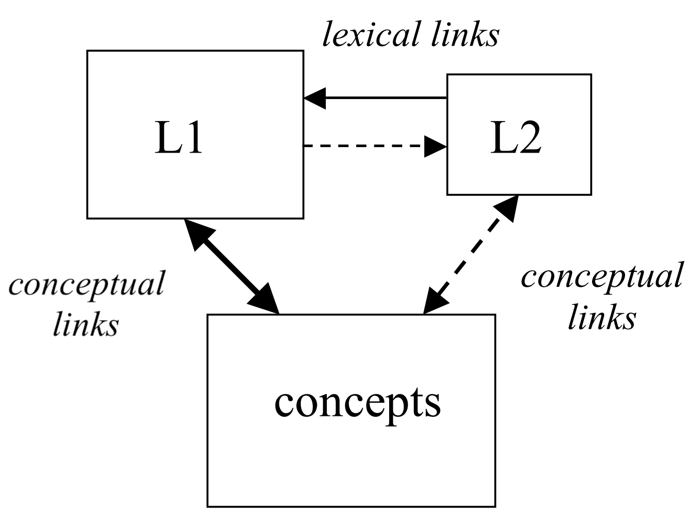

Figure 1. The Revised Hierarchical Model (Kroll & Stewart, 1994).

During a translation task in which the words have multiple translations, the presentation of a word activates two or more possible translations for that word. The additional translations of the word give the person a choice of which word to use as a response. This attributes the slower response times in Tokowicz and Kroll (in press) to the extra time necessary to resolve the competition between the different translations of a word. Working memory span and interference thus present an interesting addition to the translation process: because the bilingual activates several translations of a word and has to choose one word with which to respond, a bilingual with a higher working memory span will be able to actively hold more possible translations of a word in mind at once. A bilingual experiencing less interference will be more easily able to "turn off" the additional possible translations of a word.

The present study therefore examines the effects of individual differences and concreteness on translating words with more than one translation. In a group of English-Spanish bilinguals, we first measured working memory span and interference by an operation word span task and a Stroop task, respectively. The participants then completed a translation task with English and Spanish words varying in ambiguity, concreteness, and number of translations.

Based on past research and models of language processing, our hypotheses are as follows: first, we predict that words with multiple translations will be translated more slowly than words with one commonly accepted translation due to the extra time required to activate additional translations of the word and choose one as a response. Next, we predict that concrete words will be translated more quickly than abstract words because of the more direct links to their translation equivalents and because they are less likely than abstract words to have multiple translations.

With regards to individual differences among bilinguals, we first predict that individuals with higher working memory span, regardless of L2 vocabulary knowledge, should have longer translation latencies in the translation task for words with more than one translation. Having a higher working memory span allows these bilinguals to activate all the possible meanings of the word at once, thereby causing longer response times because of the extra time needed to resolve the competition between the multiple possible translations. Individuals with lower working memory span will have faster response times because they cannot activate all the possible translations of a word at once, and may just respond with the first word they access. We also hypothesize that individuals who are better able to maintain activation of relevant information in the Stroop task will be better adept at obstructing the alternative translations of a word with multiple translations, when faced with a choice of words to respond with in a translation task. In other words, they will be better suited to block the interference caused by accessing several possible translations. This should make those people better L2 learners because they will be able to access only the relevant characteristics of a word or concept, and inhibit the use of irrelevant translations. More simply, the individuals who perform better in the Stroop task and worse in the operation span task should perform the best in the translation task for the words with multiple translations. These results will be examined after controlling for the effects of word knowledge, which is thought to differ between people with higher and lower working memory span. We will do this using procedures established by Tokowicz et al. (2004).

METHOD

Participants

Participants were 29 native English speakers from the University of Pittsburgh, ages 18-22, who had studied Spanish as a second language for a minimum of four years. All were paid $6 for their participation in the experiment. Data from nine participants were excluded due to technical errors or failure to meet the criteria for the study. The final analyses were conducted on the remaining 20 participants.

Procedure

This experiment had four parts. Participants first completed an operation word span task followed by a Stroop task. Then, participants performed a translation production task in which they translated single words as they were presented on a computer screen from English to Spanish and from Spanish to English; the order of the two language directions was counterbalanced across participants. After completing the experimental portions of the study, participants completed a language history questionnaire.

Operation Word Span

In this task, participants were presented with a series of mathematical operations with either correct or incorrect answers (for example, 4/2 + 3 = 5). If the equation was correct, participants were instructed to press the key marked "Y" for "yes" with the left index finger. If the equation was incorrect, participants were instructed to press the key marked "N" for "no" with the right index finger. After the participant made a response, the computer presented a word in English. After each set of operations and words, the word "RECALL" was presented on the screen. Participants were then instructed to type as many words from that set as they could remember.

The critical blocks consisted of sets of operations and words ranging from two to six, with three sets of each size, making 15 critical samples in all. Each sample was presented in sequential order, with the order of equations within sets presented randomly. The participants were given two practice blocks prior to beginning the critical trials. The first practice trial consisted of four operations and words (two correct operations, two incorrect). The second practice trial contained six sample operations and words (three correct operations, three incorrect). The computer presented the operations within sets in a random order. The two practice samples were presented in sequential selection. The participants were informed when the practice trials were complete and the critical trials were about to begin.

The response times were recorded by the computer program. The participants were presented with a fixation sign (+) for 1000 ms which indicated the trial was about to begin. The equations were presented for 2500 ms, followed by a question mark (?) appearing for 1250 ms. Participants were instructed to respond to the equation as quickly and as accurately as possible. If no response was made after 1250 ms, the response was considered incorrect. After the equations were presented and the participants responded "yes" or "no," the computer presented a word in English for 1250 ms. During recall, the participants were told to write the words in order, but to try not to worry if they could not remember the order of the words. Participants were told that there was a time limit on the recall section, so they should respond as quickly as possible. When they were finished typing, the participants pressed the space bar to begin the next set.

Stroop Task

Participants were presented with stimuli on a computer screen that were either color names or rows of X's. Their task was to say out loud the color of the ink in which the stimulus was presented, not what the word actually was. They were instructed to speak loudly and clearly because their responses were recorded for later coding of accuracy. They were then given six practice trials. On each trial, a fixation sign (+) was presented for 1000 ms, after which the stimulus was presented for 5000 ms or until the participant made a response. The participant needed to respond by saying the color of the ink out loud, and then the correct answer was shown for 10 seconds or until he or she pressed a computer key to move on. The participants were informed when the practice trials were over and the critical trials were beginning. The critical trials consisted of 60 stimuli. During these trials, the fixation sign was presented for 1000 ms and each stimulus was presented for 10 seconds or until the participant made a response. No feedback explanations were given during the critical trials.

The Stroop task consisted of a series of incongruent, congruent, and neutral trials. For correct responses only, the Stroop interference magnitude for each subject was calculated by computing the quantity (incongruent reaction time minus the average of congruent and neutral reaction times) divided by the overall average reaction time. This provides a measure of how much interference the participant experienced in relation to how fast or slow they performed the task. Therefore, participants with higher Stroop measures experienced a higher magnitude of interference (in other words, they were less capable of suppressing irrelevant information in the task).

Translation Task

In this task, there were two lists of 239 stimulus words each, with all of the words varying in concreteness and number of translations from English to Spanish and/or Spanish to English. The words were divided into two lists (A and B); each participant translated one list from English to Spanish and the other from Spanish to English. Both lists were matched by word length, frequency, and number of translations.

Participants were instructed to translate the words as they were presented on the screen, as quickly and as accurately as possible. Before beginning sections of critical trials, they were informed of the direction of translation (either English to Spanish or Spanish to English). The stimuli were presented in a different random order for each participant. For the later coding of accuracy, the actual responses were tape recorded and the response times were measured by the computer from the onset of the stimulus to the onset of articulation. If the participant did not know the translation, he or she was instructed to guess or say simply “no” or “I don’t know.” The instructions also asked to avoid saying “um” or making any other noises that the computer could consider a response. The participants were given a block of practice trials consisting of eight sample words presented in random order before the critical trials. After the instructions, the participants were presented with a fixation sign (+). They were instructed to hit any key for a stimulus word to appear. The word remained on the computer screen for 4000 ms or until the participant responded. At the onset of the vocal response, the stimulus word disappeared from the screen and the fixation sign reappeared to lead into the next trial. The participants were informed when the practice block was over and told the critical trials were about to begin. After all the words were presented, the participants were thanked for their participation.

Stimuli

The 478 stimulus words in this task were divided into two lists (A and B), such that one group of participants translated one list of words from English to Spanish and the other group of participants translated the same words from Spanish to English. Within each list, the words were presented in a randomized order to each participant.

The stimuli consisted of cognates, non-cognates, and false cognates. Cognates and false cognates with multiple translations are not processed the same way as other words with multiple translations, and would not be a valid way to test our hypotheses. Therefore, cognates and false cognates were treated as filler items and were not analyzed. Thus the critical items were the 287 non-cognates. Properties of the stimulus words can be seen in Table 1.

Table 1. Properties of the Stimulus Words

	Cognates	False cognates	Non-cognates	Total
Average length (English)	6.48	6.75	5.38	5.82
Average length (Spanish)	6.75	5.25	5.99	6.27
Average number of translations (E to S)	1.03	1.25	1.18	1.12
Average number of translations (S to E)	1.09	1.00	1.17	1.14
Average English frequency	64.00	79.50	102.52	87.35

Note. Lengths are given in number of letters. Frequencies are given as number of occurrences per million.

Language History Questionnaire

After the other tasks had been completed, participants were asked to fill out a language history questionnaire. The questionnaire asked participants to rate their proficiencies in English and Spanish on a scale of one (worst) to ten (best) in four categories: reading, writing, conversational abilities, and speech comprehension. There were also questions relating to the participants' experience in learning the second language, and any other languages the participant may have learned. Upon completion of the questionnaire, participants were thanked for their participation and debriefed in the purpose of the study. Information from the questionnaires can be found in Table 2.

Table 2. Language History Questionnaire Data

	Working Memory Span		
	Low Span (< 39.95)	High Span (> 39.95)	Overall
# Participants	10	10	20
Age Began L2 (years)	12.80 (1.23)	13.50 (1.65)	12.47 (3.15)
Time Studied L2 (years)	6.80 (1.48)	6.00 (1.94)	6.38 (1.69)
Interference Measure	0.15 (0.08)	0.15 (0.07)	0.15 (0.07)
Time Abroad in L2 country (months)	1.85 (2.15)	2.45 (4.55)	2.10 (3.47)
Time Abroad Total (months)	2.35 (2.07)	3.05 (4.41)	2.70 (3.37)
L1 Abilities			
Reading	9.90 (0.32)	9.70 (0.48)	9.80 (0.41)
Writing	9.55 (0.60)	9.60 (0.52)	9.58 (0.54)
Conversational	9.90 (0.32)	9.80 (0.42)	9.85 (0.37)
Speech Comprehension	9.80 (0.42)	9.70 (0.48)	9.75 (0.44)
L2 Abilities			
Reading	6.65 (1.45)	7.40 (1.43)	7.03 (1.46)
Writing	6.35 (1.89)	6.50 (1.27)	6.43 (1.57)
Conversational	6.10 (1.60)	7.10 (1.67)	6.60 (1.67)
Speech Comprehension	6.50 (1.78)	7.50 (1.08)	7.00 (1.52)

Note. For descriptive purposes only, participants were classified as being “high span” or “low span” based on whether they were above or below the mean span number (39.95). Standard deviations are given in parentheses.

RESULTS

All of the data were analyzed with hierarchical linear regressions. This type of regression allows us to examine the effects of certain predictors above and beyond that of other predictors. The dependent variable was reaction time, which we attempted to explain using several variables: the covariates length of stimulus word, length of response word, log frequency, accuracy in both directions of translation (L1-to-L2 or L2-to-L1), and participant number; and the independent variables direction of translation, concreteness, interference measure, working memory span, and the number of translations of both the stimulus word and response word. Accuracy was entered as a covariate in order for the regression to show the effects of other regressors relevant to each participant and what he or she knows, and to control for knowledge differences between high and low span bilinguals. Because we were simultaneously examining item-specific and person-specific effects, we could not use means across items or people and thus entered participant number as a covariate. This allowed us to examine a participant's performance on certain items relative to his or her overall performance. We also looked at two-, three-, four-, five-, and six-way higher order interactions.

We computed some preliminary regressions first to determine which variables explained the most variance and should be used in the main analyses. In doing so, we found a correlation between the three ratings (familiarity, context availability, and concreteness) that caused a suppression effect. Using three separate regressions, each with a different rating, we determined that concreteness explained the most variance (R^2 = 0.141). Because of the suppression effect, we removed the other ratings variables from the analyses and all further analyses used only the concreteness rating. Using this particular factor makes our results comparable to those of previous studies, most of which used the concreteness rating in the analyses.

The steps of the main regression were significant up to the level in which two-way interactions were entered, $\Delta R^2 = .015$, $F(20, 2006) = 1.781$, $p < .05$. As expected, number of translations for both the stimulus and response words significantly predicted reaction time, such that reaction time increased as the number of translations increased,

$\Delta R^2 = .005$, $F\ (2, 2028) = 6.167$, $p < .01$. Both working memory span and the interference measure predicted response times, $\Delta R^2 = .007$, $F\ (2, 2026) = 7.991$, $p < .01$. This indicates that as working memory span increases, reaction times increase. Reaction times also increase as the level of Stroop-demonstrated interference increases. This was consistent with our hypotheses.

Four two-way interactions were significant, namely log frequency x interference measure, direction of translation x concreteness, direction of translation x number of stimulus word translations, and interference measure x span number (all *p*'s < .05). To gauge the effects of the interactions, we computed high and low values for each variable of interest by adding and subtracting one standard deviation from the mean value. These high and low values were used in the regression equation and the resulting estimated reaction times plotted in each of the figures.

The interference x span interaction is the most relevant to this study, and arguably the most interesting. Those individuals with lower Stroop numbers (less interference) were faster overall than low span bilinguals. The fastest translations were produced by bilinguals who were both low interference and low span. Moreover, bilinguals who were both high interference and high span were significantly slower to translate all words overall, regardless of whether words were abstract or concrete (see Figure 2).

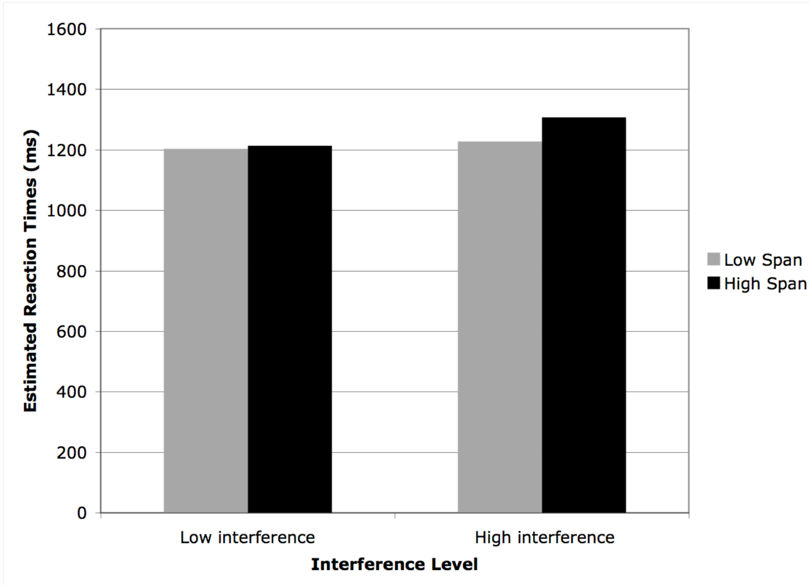

Figure 2. Estimated translation times by working memory span and interference.

The direction of translation significantly interacted with both number of stimulus word translations and concreteness. As has previously been demonstrated, backward direction (L2-to-L1) was performed more quickly than forward translation (L1-to-L2), regardless of number of translations or concreteness. In backward translation, the number of stimulus word translations did not have much of an effect (see Figure 3). However, when translating in the forward direction, words with multiple translations were translated more slowly.

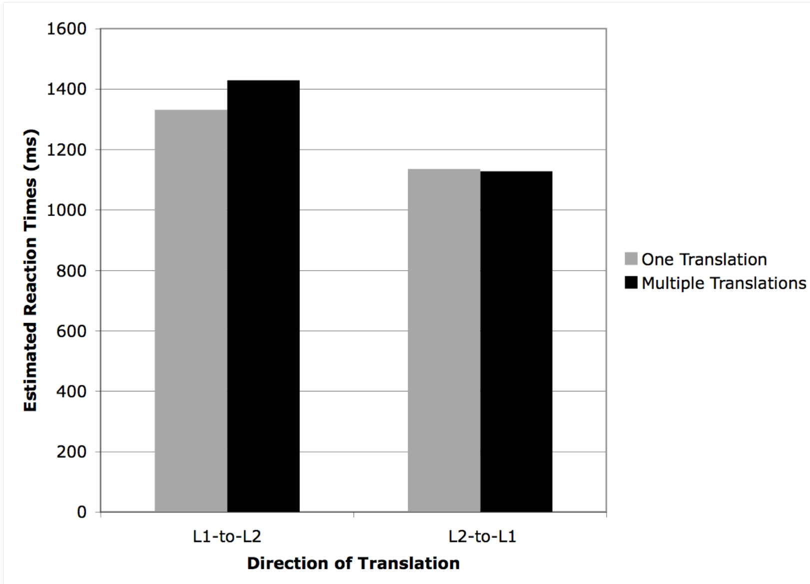

Figure 3. Estimated translation times by direction and number of stimulus word translations.

The direction x concreteness interaction showed the slowest reaction times to be for words with low concreteness in the forward direction. Highly concrete words in the same direction were slightly quicker. The fastest condition of this interaction occurred for low concrete words in L2-to-L1 (see Figure 4). For this condition, however, it is important to keep in mind that the concreteness rating is of the English word only. Thus, in forward translation, the concreteness rating describes the stimulus word, whereas in backward translation, it describes the response word.

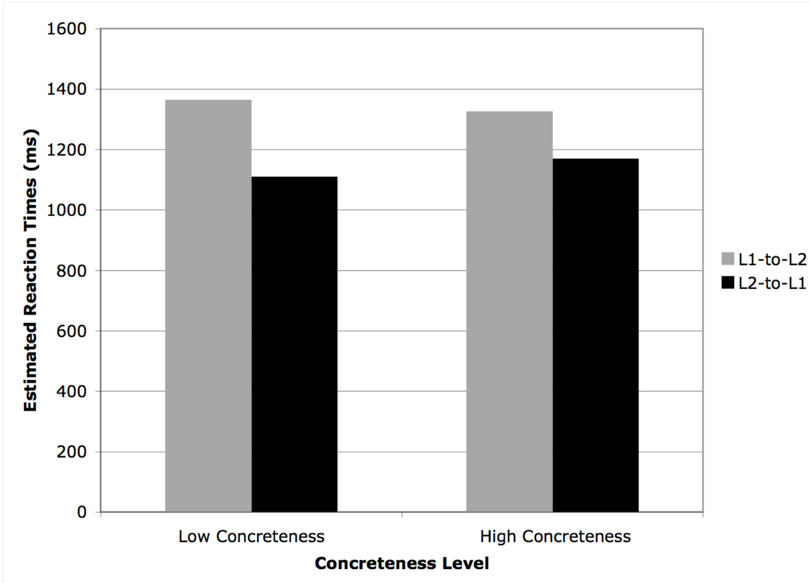

Figure 4. Estimated translation times by direction and concreteness.

The interference measure significantly interacted with the log frequency of the word such that interference slowed down the translation times for low frequency words (see Figure 5). High frequency words were translated faster and were relatively unaffected by differences in Stroop-measured interference.

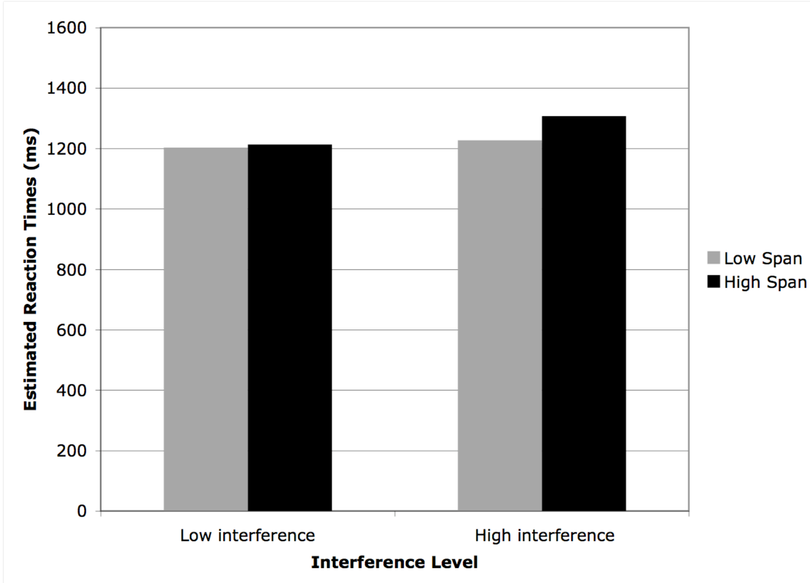

Figure 5. Estimated translation times by English word log frequency and interference levels.

Accuracy rates were examined separately. As working memory span increased, the percentage of correct responses increased (see Figure 6). Accuracy rates decreased as interference levels increased (see Figure 7). For discussion purposes, participants were classified as high or low span and high or low interference based on whether or not they were above or below the mean span number (39.95) or above or below the median interference number (0.1642). The accuracy rates of each of the four groups can be seen in Figure 8.

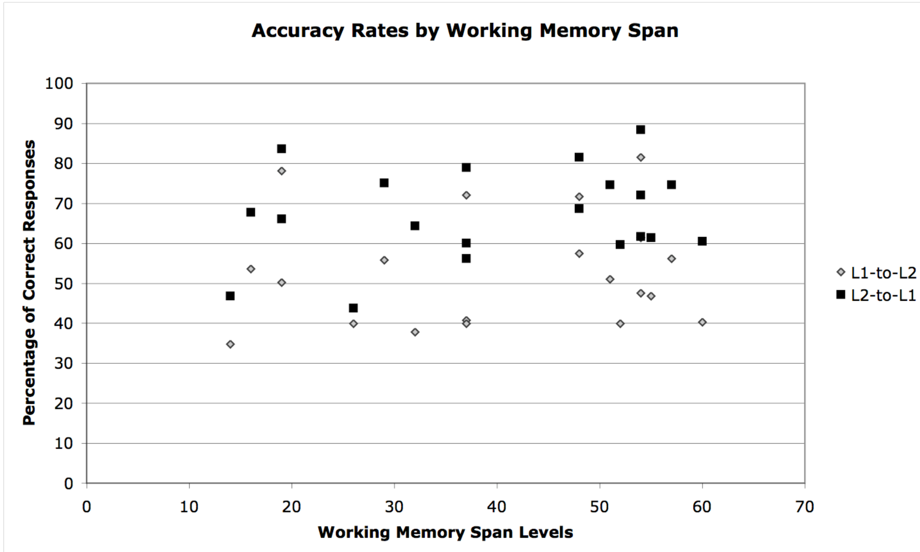

Figure 6. Accuracy rates by working memory span levels.

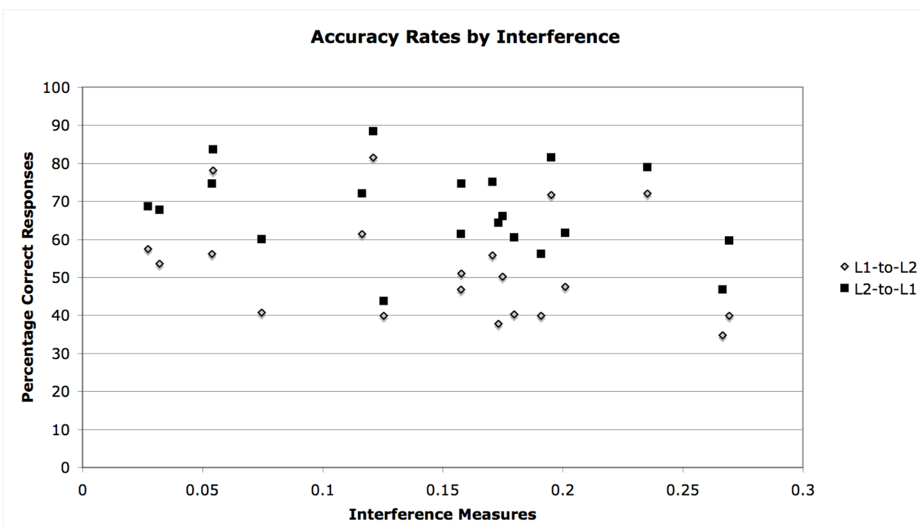

Figure 7. Accuracy rates by interference levels.

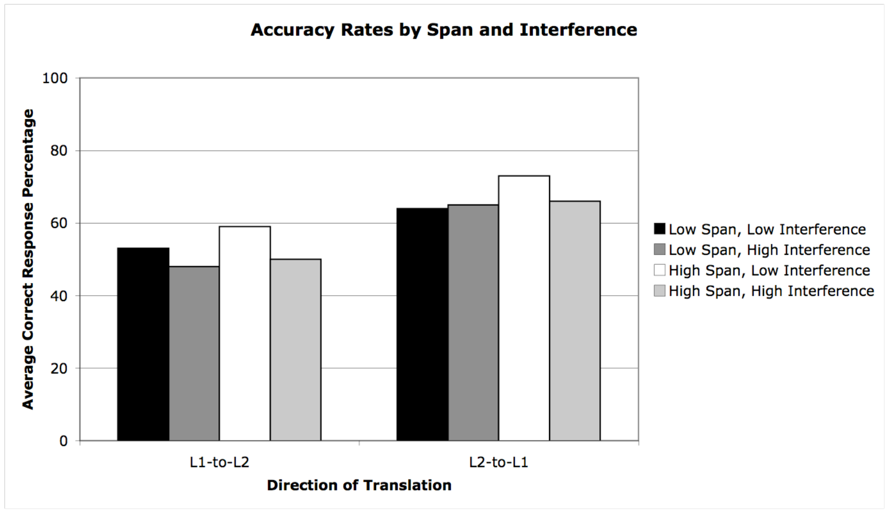

Figure 8. Accuracy rates by span and interference levels in each direction of translation.

GENERAL DISCUSSION

The findings of this study were consistent with several of our hypotheses. Generally, words that have multiple translations were translated more slowly than words that have a single, commonly-accepted translation (e.g., Tokowicz & Kroll, in press). In addition, reaction times were reliably predicted by individual differences in cognitive capacities.

Having a *lower* working memory span seemed to allow bilinguals to more quickly translate all words in the translation task, not just the words with multiple translations. As expected, because these individuals are less capable of holding a great deal of information in memory at once, their translation performance was not hindered when words had multiple translations. Because of the inability to cognitively hold the many possible translations of a word at once, low span individuals may have simply activated a possible translation in the target language and responded.

The data suggest that high span bilinguals were subject to competition among possible translations. Having a high working memory span slowed the response times in the translation task. Because these individuals are capable of holding more pieces of information in memory at once, they are likely to activate several possible translations of a word that has multiple translations. These individuals then have to select only one translation with which to respond. The slower response times are likely due to the extra time needed to resolve the competition between the possible translations.

There is sufficient reason to believe that this extra time needed in translation production is due to higher working memory span as opposed to proficiency. In entering accuracy as a covariate early in the regression steps, we essentially eliminated the effects caused by differing word knowledge among participants. Moreover, Tokowicz (2005) found that more proficient bilinguals translated words faster than less proficient bilinguals, but the difference was much more pronounced for words with one translation. In our study, we did not find a significant interaction between span and number of translations; the effects of working memory span held for all translations, regardless of whether they had single or multiple translations.

Stroop-measured interference affected reaction times in much the same way. Individuals subject to more interference showed longer reaction times, suggesting that they are attending to extra information during the translation process that slows them down. Bilinguals better adept at blocking interference were quicker to produce translations, suggesting they are more capable of selectively focusing on only the important information necessary to complete the task.

Furthermore, the interaction between the Stroop and span measures suggests that translation abilities are greatly affected by individual cognitive differences. Individuals who are less susceptible to interference and at the same time are less capable of holding several pieces of information in memory at once are the fastest to produce a translation in this type of task. Having a high working memory span and experiencing greater levels of interference significantly slows the translation process, regardless of number of translations. Therefore, this finding transcends our prediction for only multiple translation words, and suggests that varying cognitive abilities affect other aspects of language production as well.

These findings have several implications for language learning and processing. Low span, low interference individuals were the fastest in translating single words in a translation task; does this necessarily make an individual a more effective communicator? Tokowicz et al. (2004) found that individuals with higher working memory capacities were better able to circumlocute a word in the absence of knowing an exact word-to-word translation, which may make them better able to communicate. If higher span bilinguals are able to process many pieces of information relevant to meaning to effectively communicate, it may not be necessary to be able to perform faster single word translations. Expanding on this idea, high span and low interference individuals may be the best communicators.

Not surprisingly, the accuracy rates for the translation task did not follow the same pattern as the translation latencies. As Figure 5 shows, there was a general trend upward in accuracy rates as bilinguals' working memory spans increased. Also, accuracy rates trended downward as interference levels increased. The most accurate individuals in both directions of translation were those who were high span *and* low interference, even though they were not necessarily the fastest. Producing accurate responses in a translation task is only one portion of proficiency; but having a high span and being subject to lower levels of interference may help an individual be better in other areas of L2 proficiency as well. Interestingly, in the language history questionnaire, high span bilinguals rated themselves higher than low span bilinguals in every category of L2 proficiency (see Table 2). The average interference levels were the same across all groups; this shows that having a high working memory capacity, regardless of interference level, may be more beneficial for proficient language processing than previously thought.

Having a high span allows for more complex processing of explanatory words to convey a meaning or idea, and being less susceptible to interference could facilitate the inactivation of irrelevant meanings or ideas. This may help an individual express a more complex thought in an L2 even when certain words in the L1 idea are unknown. This may also help an individual better understand spoken L2. A higher working memory span enables the individual to process the many pieces of the spoken language at once, and the low interference helps inhibit the information that is not relevant to understanding the overall meaning of the words. This would help a person be able to more easily infer the meaning of an unknown word or use the context of speech to understand the overall idea of what is being said. Further research could more thoroughly examine how different aspects of proficiency change as a function of individual differences.

Interference by itself reliably slowed translation times for low frequency words. Words that are lower frequency are generally not used as often and may not be as familiar or concrete (e.g., Prior et al., in press). For this reason, lower frequency words were overall more slowly translated than high frequency words, but it is interesting that the high-interference bilinguals were most affected. Moreover, these two measures interacted for all words, not only words with multiple translations. This finding suggests that the high interference bilinguals are activating other characteristics of the word that may be irrelevant, and attending to this additional information slows translation production time.

Not enough information from this study is available to definitively conclude that the mechanism of translation for low span, low interference bilinguals is by a more direct, lower-level processing of the word and its translation equivalent. Similarly, high interference individuals may not be slower because they are subjected to many pieces of distractor information, but they may be processing the translation at a higher cognitive level. If these individuals are more likely to conceptually mediate the word in order to produce a translation, the RHM would predict slower translation (Kroll & Stewart, 1994).

Another model of the bilingual system is Green's Inhibitory Control Model (1998). As its name suggests, this model attributes the ability to use two distinct languages and switch between them comes from the ability to inhibit additional activated information that is not necessary to perform the task at hand. If our present interference measure is an equal measure of inhibition abilities, our results also support Green's model. The IC Model predicts that a translation task poses a selection problem to the bilingual directly related to what information is available in both L1 and L2. Green proposes that there are always many activated pieces of information in both L1 and L2, and the bilingual must reactively control which pieces to suppress in order to use one language or switch between the two. It follows that the individuals in the present study who are better able to block interference are more quickly resolving the competition between two or more words, or are more quickly inhibiting the additional active information that is not necessary to produce a translation.

Interestingly, the interference measure interacted with word frequency but the span measure did not. In the past, working memory tasks have been used more often than interference or inhibition tasks in language studies; perhaps these new results should act as evidence to language researchers to begin using Stroop-tested interference measures in future L2 studies.

The concreteness interaction poses several interesting aspects of L2 processing. Concreteness alone did not reliably predict reaction time, but it did interact significantly with direction of translation such that concreteness actually slowed down translation in the L2-to-L1 direction. Although this is not consistent with our initial hypothesis, it is consistent with the reversal of the concreteness effect found in Tokowicz & Kroll (in press). In that study, higher concreteness facilitated faster translation of words with multiple translations, but actually slowed reaction times for words with only one translation. This new finding of the reversal of the concreteness effect can be taken as further evidence that word ambiguity significantly affects language processing and may confound results of studies that do not separate concrete and abstract words.

These results can also have significant applications to language learning. Most L2 learning at the adult level takes place in a classroom setting, with a strong reliance on vocabulary lists. This forms strong lexical level links between L1 and L2, and, especially during early instruction, focuses on concrete, unambiguous words. The results of Tokowicz and Kroll (in press) also suggest that participants knew more concrete than abstract L2 vocabulary words. Perhaps presenting words with multiple translations earlier in L2 instruction would help language learners become more familiar with these words, allowing for quicker access of their translations in order to facilitate more fluid language proficiency.

Language instruction can also be tailored to different learners based on their working memory capacities and inhibition skills. People who experience less interference will be better L2 learners than those who do not have strong inhibition skills, by virtue of being able to focus only on what is necessary to learn a piece of another language. Individuals more susceptible to interference may need more exposure to certain aspects of an L2 during learning, or may need an adapted form of instruction. More research in this particular area will help develop better teaching methods to cater to different types of learners.

One aspect of translation that was not addressed in this study was the type of error made during translation production. We conducted our main analyses with only correct responses and did not examine the types of errors made; we also showed that the individual differences that facilitated faster translation did not facilitate greater accuracy. However, it may be possible that the type of multiple translation influences the type of error or production of a translation equivalent. Perhaps certain types of multiple translations are prone to specific types of errors, and bilinguals of varying spans and interference levels would be more likely to commit certain types of errors. Tokowicz et al. (2004) found that high span bilinguals were more likely to make meaning errors, whereas low span bilinguals were more likely to make non-response errors. Combined with the results of this study, it is likely that high span individuals would make more errors relating to the ability to being able to process several pieces of information at once. For example, when presented with the word “dog” in a translation task a high span individual is likely to activate the characteristics animal, four legs, and furry, he or she also may activate its lexical neighbors such as log or dig. A low span individual may only activate its translation equivalent, “perro.” Interference levels may affect to what degree these distracting pieces of information produce errors. Types of errors made during translation by different individuals should be addressed in future studies.

In conclusion, the findings of this study support previous research suggesting that words with multiple translations are processed more slowly than words with one, commonly-accepted translation. They also provide evidence that individual differences in cognitive abilities cause bilinguals to process language differently. We have shown that working memory span and interference can have significant implications for translation production in English and Spanish. A bilingual with a high span experiencing more interference is slower to translate words, regardless of the number of translations or concreteness. Yet, a bilingual with high span and low interference is likely to be the most accurate in the task. As we proposed earlier, the additional production time may be due to a deeper processing of the translation words; faster translation may not necessarily be better translation.

FOOTNOTES

1. For the purposes of this study, we are only interested in the general mechanism of working memory span, and not whether this mechanism is produced as a result of having a higher or lower “capacity”. Therefore, we use the term “working memory span” to refer to the general phenomena.

2. Again, we are only interested in the control the individual has over which pieces of information are active and which he or she ignores. Thus, we remain agnostic about any possible differences between “inhibition of irrelevant information” and “activation of relevant information” and will use the term “interference” in this paper to refer to the general mechanism.

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