SHARED TRANSLATION PAIRS PROCESSING IN BILINGUALS: AN EVENT-RELATED POTENTIAL STUDY

by

Avani Kolla

Bachelor of Philosophy, University of Pittsburgh, 2016

Submitted to the Undergraduate and Graduate Faculty of
the Dietrich School of Arts and Sciences in partial fulfillment of
the requirements for the degree of
Bachelor of Philosophy

University of Pittsburgh
2016

UNIVERSITY OF PITTSBURGH

DIETRICH SCHOOL OF ARTS AND SCIENCES

This thesis was presented

by

Avani Manasa Kolla

It was defended on

April 28, 2016

and approved by

Julie Fiez, University of Pittsburgh, Departments of Psychology, Neuroscience, and Communication Sciences and Disorders

Barbara Malt, Lehigh University, Department of Psychology

Tessa Warren, University of Pittsburgh, Departments of Psychology, Linguistics, and Communication Science and Disorders

Thesis Advisor: Natasha Tokowicz, University of Pittsburgh, Departments of Psychology and Linguistics

SHARED TRANSLATION PAIRS PROCESSING IN BILINGUALS: AN EVENT-RELATED POTENTIAL STUDY

Avani Kolla, BPhil

University of Pittsburgh, 2016

This study explores the question of how first language (L1) processing interacts with second language (L2) processing and how the two languages are integrated in a bilingual's mind. More specifically, we investigate the nature of the relationship (inhibitory vs. facilitative and semantic vs. lexical) between shared translation pairs (e.g., "doll" and "wrist" both translate to "muñeca" in Spanish). If there is a facilitative relationship, when one translation is encountered, the mental representations of both translations would be activated. If there is an inhibitory relationship, encountering one translation would suppress the mental activation of the second translation. A relationship between shared translation pairs, regardless of whether it is inhibitory or facilitative, would suggest integration between first and second language processing. We also explore whether this relationship occurs at the semantic or lexical level, and whether it is dependent on level of semantic relatedness. Event related potentials (ERPs) were recorded as English monolinguals, English-Spanish bilinguals, and Spanish-English bilinguals performed a lexical decision task (LDT). The LDT prime-target pairs included shared translation pairs, different translation pairs, and pairs matched on lexical variables. Each type of pair included highly related, moderately related, and unrelated prime-targets. This study was done in two parts: 1) design of experiment, first wave of data collection, and preliminary analysis, and, 2) stimulus optimization, reanalysis of first wave data, a second wave of data collection, and analysis of the larger dataset. This paper focuses on the second part of the study. Analysis of N400 waveforms (taken to be reflective of semantic processing) generated by the first wave of participants revealed larger N400 amplitudes for shared translation pairs than matched pairs. This suggests an inhibitory relationship between shared translation pairs. However, analysis of N400 waveforms generated by first and second wave participants revealed no interaction between translation status (matched and shared) and linguistic background group (monolingual and bilingual). Comparison of first wave and second wave participants' characteristics suggests that the balance between first and second language proficiencies influences the degree of L1-L2 semantic integration.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PREFACE

Thank you to Julie Fiez for serving on my committee.

Thank you to Barbara Malt for serving on my committee.

Thank you to Tessa Warren for serving on my committee.

Thank you to the University of Pittsburgh Honors College for supporting and funding this project.

Thank you to the graduate and undergraduate members of the PLUM Lab for their assistance ERP collection and behavioral data coding.

Thank you to Tamar Degani for designing this experiment and guiding me through the data collection and analysis process.

A very special thank you to Natasha Tokowicz for being my thesis advisor and supporting me throughout my entire research project.

1.0 INTRODUCTION

Exploration of the bilingual brain raises the question of whether or not first language (L1) processing interacts with second language (L2) processing. Current bilingual language processing models support the idea of interplay between L1 and L2 processing (Kroll, Bobb & Hoshino, 2014). The Bilingual Interactive (BIA) Model (Dijkstra & Van Heuven, 1998; Van Heuven, Dijkstra, & Grainger, 1998, as cited in Thomas & van Heuven, 2005) assumes that the lexicon, or mental dictionary, is integrated across languages. This model also assumes lexical access is parallel and nonselective at the lexical level. Thus, seeing an L1 word will simultaneously activate the L1 and L2 mental representations in the lexicon. The BIA+ Model (Dijkstra & Van Heuven, 2002, as cited in Murre, 2005) extends parallel access to phonological and semantic representations (Murre, 2005). A number of studies using interlingual homographs (e.g., the word "angel" has different meanings in English and Dutch), cognates (e.g., the English word "rich" and its similarly spelled Spanish translation, "rico"), and other cross-language materials have supported the model of an integrated lexicon (Duñabeitia, Perea & Carreiras, 2010; Kerkhofs, Dijkstra, Chwilla & Bruijn, 2006; Marian & Spivey, 2003).

Shared translation pairs are another way to explore the interplay between L1 and L2 processing. Shared translation pairs are a result of translation ambiguity, which can arise in many ways (Prior, MacWhinney & Kroll, 2007). One way translation ambiguity can arise is from polysemous words (words that have more than one meaning); two different concepts that are linked to two distinct words in one language may translate to a single polysemous word in another language (Youn, Sutton, Smith, Moore, Wilkins, Maddieson, Croft & Bhattacharya, 2015). For example, the shared translation pairs “doll” and “wrist” are distinct words in English yet both translate to “muñeca” in Spanish. Translation ambiguity can also be a result of synonyms in one language translating to a single word in another language. For example, the shared translation pairs “couch” and “sofa” are synonyms in English that both translate to “sofá” in Spanish. Thus, a relationship between L1 shared translation pairs only exists if L2 influence is taken into account. Under the BIA+ Model, the words “doll” and “wrist” would both activate the mental representation of “muñeca” (Murre, 2005).

Shared translation pairs have been used in a number of recent studies (Prior et al., 2007). However, it is still unclear whether shared translation pairs share an inhibitory connection (e.g., Elston-Güttler, Paulmann & Kotz, 2005) or a facilitative connection (e.g., Degani, Prior & Tokowicz, 2011). A facilitative connection could arise from coactivation of shared translation pairs. When the shared translation (“muñeca”) is encountered in a context in which it means “doll,” the mental representations of both translations (“doll” and “wrist”) are activated. This coactivation strengthens the link between the mental representations for both translations; exposure to one translation would facilitate the processing of the other translation. In an inhibitory connection, activation of one mental representation (“doll”) suppresses the mental representation of the other (“wrist”). Under this model, encountering the shared translation, “muñeca” in a context in which it means “doll,” the mental representation for “doll” is activated, whereas the representation for the incorrect translation “wrist” is suppressed (Degani et al., 2011). This inhibits the link between the two mental representations. It also unclear whether the relationship between shared translation pairs is lexical (e.g., Elston-Guttler et al., 2005) or semantic (e.g., Degani et al., 2011). In addition, shared translation pairs can be divided into level of semantic relatedness. For example, “wrist” and “doll” are unrelated whereas “talk” and “speak,” which both translate to “hablar,” are highly related.

This study is the first event-related potential (ERP) study to investigate the relationship between shared translation pairs using semantic relatedness as a variable. It is also the first ERP study to use Spanish-English and English-Spanish bilinguals and extend past research on shared translation pairs to Spanish-English word pairs. However, the main focus of this study is to further examine whether the relationship between shared translation pairs is inhibitory or facilitative, and lexical or semantic. Exploring the nature of this relationship will provide insight on how L1 processing and L2 processing interact.

To investigate the relationship between shared translation pairs, we analyzed the effect of shared translation pairs on ERP N400 waveform amplitudes generated by bilinguals during a lexical decision task (LDT). This study was done in two parts. The first part included designing the study, the first wave of ERP collection, and preliminary analysis. The second part, which is the focus of this paper, included stimulus optimization, a second wave of ERP collection, and reanalysis. The experimental design and LDT stimuli were the same for both the first wave and second wave participants. However, re-analysis of first wave data and analysis of the larger dataset only included ERPs generated from the optimized stimuli.

ERPs are derived from an electroencephalogram, which records electrical activity of the brain (Kutas & Federmeier, 2009). More specifically, ERPs are small voltages generated in the brain in response to stimuli that can be used to explore the temporal course of language processing (Sur & Sinha, 2009; Kutas, Federmeier, Coulson, King & Muente, 2000). Thus, mean ERP amplitudes may be indicative of the mean postsynaptic potential, number of neurons activated, or degree of synchrony among neurons at a specific point in time (Kutas & Federmeier, 2009).

The N400 waveform is the mean amplitude that occurs between 300 and 500ms after a stimulus is encountered. Previous ERP studies have shown that the N400 waveform could reflect lexical and/or semantic processing. One possible explanation is that the N400 waveform reflects brain activity at the junction of the two levels of processing (Kutas & Federmeier, 2011; Laszlo & Federmeier, 2011). Another explanation is that the N400 waveform involves both lexical and semantic processing but is more sensitive to changes in the latter (Perrin & García-Larrea, 2003; Thierry & Wu, 2007). In general, the amplitude of the N400 waveform is smaller for stimuli that are more expected, easier to process, or more closely linked (e.g., coactivated) (Kutas & Federmeier, 2011). Thus, if shared translation pairs have a facilitative relationship, they would have N400s with smaller amplitudes. Alternatively, if shared translation pairs have an inhibitory relationship, they would have larger N400 amplitudes because exposure to one translation would inhibit the other, making it more difficult to process.

A literature review of studies using interlingual homographs suggested that ambiguous words are either coactived or inhibited. Interlingual homographs are a form of cross-language ambiguity, in which a word in one language has a different meaning in another language (e.g., “fin” in Spanish means “end”). The literature review demonstrated that in some studies, all representations (“fin” in regards to fish and “fin” meaning “end”) for the word, even across languages, were coactivated. In other studies, the inappropriate representation appeared to be inhibited (Degani & Tokowicz, 2010). Because shared translation pairs are also a form of ambiguity involving two languages, the findings of the literature review can be applied to the present study to suggest that there is coactivation or inhibition of the multiple representations (“wrist” and “doll”) of an ambiguous shared translation (“muñeca”). Coactivation would result in a facilitative relationship, whereas inhibition of the inappropriate representation would result in an inhibitory relationship. Thus, Degani and Tokowicz’s literature review provides evidence that there is either a facilitative or inhibitory relationship between shared translation pairs.

In a study, Jiang (2002) provided further evidence that a relationship between shared translation pairs exists. In the study, Chinese-English bilinguals and English monolinguals rated the degree of semantic relatedness of English word pairs. A higher rating indicated increased semantic relatedness. Jiang (2002) found that the bilinguals rated shared translation pairs as significantly more related than pairs that did not share a Chinese translation. In the same study, participants performed an online semantic judgment task. Participants had to decide if two words were semantically related or not. Jiang found that Chinese-English bilinguals responded more quickly for shared translation pairs than for different-translation pairs. These findings suggested there is a link between L2 shared translation pairs due to L1 influence. In a later study, Jiang (2004) replicated these findings and extended them to Korean-English shared translation pairs.

To test the effect of shared translation pairs on N400 amplitude, Elston-Güttler et al. (2005) had German-English bilinguals perform an LDT, which included semantically unrelated L2 prime-target pairs that shared a translation in German (e.g., “jaw” and “pine” translate to “kiefer”) and prime-target pairs that did not share a translation (e.g., “jaw” and “oak”). N400 amplitudes generated by bilinguals were not significantly different for pairs that shared a translation than for pairs that did not share a translation. However, the authors suggested that the N200 amplitude was indicative of an inhibitory relationship. An inhibitory relationship could arise because it is beneficial in determining the context in which to use each translation of the second language word (Degani et al., 2011). Because the N200 is reflective of orthographic processing, these findings suggested the relationship between shared translation pairs and influence of L1 on L2 processing occurs at the lexical level (Elston-Güttler et al., 2005).

However, more recent research has shown this relationship to be facilitative and evident at the semantic level. Thierry and Wu (2007) conducted a study in which Chinese-English bilinguals performed a semantic relatedness task on English word pairs. Some of the word pairs shared a character when translated into Chinese (e.g., “train” and “ham” translate to “huo che” and “huo tui,” respectively). The authors found that Chinese-English bilinguals generated smaller N400 amplitudes for words that shared a character in Chinese. Thierry and Wu postulated that this effect may have been due to character repetition, but suggested that it could also be due to coactivation of translation equivalents (or in this case translations that share a character).

In a related study, Degani et al. (2011) had English-Hebrew bilinguals, Hebrew-English bilinguals, and English monolinguals perform a semantic similarity rating task on English word pairs that either shared a translation or did not share a translation. The authors found that bilinguals rated both semantically related (e.g., “home” and “house”) and unrelated (e.g., “tool” and “dish”) English-Hebrew shared translation pairs as being more similar in meaning than unshared translation pairs. Degani et al. (2011) suggested that the semantic relatedness between shared translations is a result of them being coactivated every time their translation is encountered. This coactivation results in a facilitative relationship between shared translation pairs. In this relationship, an association, or stronger link, is created between semantic and/or lexical representations of shared translation, according to Hebbian principles (Hebb, 1949, as cited in Degani et al., 2011). For related shared translation pairs, this coactivation strengthens the pre-existing semantic association. For unrelated shared translation pairs, coactivation results in formation of a new association (Degani et al., 2011). Furthermore, because Degani et al.'s findings were applicable to both English-Hebrew and Hebrew-English bilinguals, there is evidence that this facilitative relationship is bidirectional. This bidirectional effect extends the findings from Jiang (2002), Elston-Güttler et al., (2005), and Thierry and Wu (2007) to suggest that not only can L1 influence L2 processing but L2 can also influence L1 processing. This bidirectional effect has been supported by a number of other studies. For example, in a study in which Russian-English bilinguals performed an L1 object naming task, Pavlenko and Malt (2011) found that L1 use of concrete nouns could be influenced by the L2.

This study uses ERPs to further explore Degani et al.'s findings on semantic relatedness and the bidirectional effect in relation to shared translation pairs. This study also builds on previous research to further investigate the relationship between shared translation pairs. Analysis of ERP N400 waveform amplitudes allows for examination of the inhibitory vs. facilitative and semantic vs. lexical nature of this relationship. ERPs were collected as English-Spanish bilinguals (with Spanish as their L2), Spanish-English bilinguals (with English as their L2), and English monolinguals performed an LDT. The LDT stimuli included shared translation pairs, nonwords, pseudowords, and matched pairs (words that do not share a translation but are matched with shared translation pairs on variables such as word length and word frequency). Shared translation and matched pairs were divided into levels of relatedness to allow for analysis of this variable. This also controlled for the N400 amplitude's sensitivity to semantic relatedness. In addition, both types of bilinguals participated in English and Spanish LDTs to explore the bidirectional nature of language influence. If shared translation pairs do affect N400 amplitude, this method of analysis would provide insight onto the model of bilingual language processing.

If bilinguals generate N400s of significantly different amplitudes for shared translation pairs than matched pairs, this would indicated lexical integration across languages because influence of a second language is necessary for shared translations to be more coactivated or more inhibited than words that do not share a translation. Based on previous N400 research, this would indicate semantic integration. If bilinguals generate smaller N400 amplitudes for shared translation pairs than matched pairs, it would indicate an facilitative relationship as suggested by Thierry and Wu (2007) and Degani et al. (2011). Alternatively, if bilinguals generate larger N400 amplitudes for shared translation pairs, it would suggest an inhibitory relationship as supported by Elston-Güttler et al. (2005). Furthermore, if an N400 effect is present for both English-Spanish and Spanish-English bilinguals, it would suggest bidirectional transfer of lexical information (Degani et al., 2011). However, due to the small sample size in this study, we are not able to effectively explore bidirectionality. If an N400 effect is present for all levels of relatedness, it would confirm Degani et al.'s findings that the relationship between shared translation pairs is independent of this variable. Lastly, if highly related shared translation pairs generate smaller N400 amplitudes than unrelated shared translation pairs, we would confirm the N400 amplitude is sensitive to level of semantic relatedness.

In addition to the LDT, participants performed an operation span task (Turner & Engle, 1989). The operation span task is a measure of working memory, or the subset of memory that allows us to keep relevant information accessible during cognitive tasks. Working memory is also related to cognitive skills such as problem solving, reasoning, and comprehension (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005). Because operation span involves the two different tasks of math and memory and the two different stimuli types of letters and numbers, it also provides an accurate assessment of multitasking ability (Sanbonmatsu, Strayer, Medeiros-

Ward, & Watson 2013). Because there is a correlation between ability to switch between languages and ability to switch between non-language tasks (Prior & Gollan, 2011), bilinguals may have an advantage in multitasking ability.

Analysis of the first wave of LDT data showed that both bilinguals and monolinguals generated smaller N400 amplitudes for English word pairs that share a translation in Spanish (e.g., “wrist” and “doll”) than for pairs that did not share a Spanish translation. Because monolinguals had no knowledge of Spanish, it was not possible that this effect was due to the influence of the Spanish shared translation (e.g., “muñeca”). Thus, these data suggested that other variables influenced N400 amplitudes and the lexical properties of shared translation pairs were significantly different from those of matched pairs. Previous research has shown that N400 waveform amplitude is influenced by lexical properties such as repetition, frequency, concreteness, semantic relatedness, and orthographic neighborhood (Kutas et al., 2000; Kutas & Federmeier, 2011). Orthographic neighborhood is defined as all the words that share all but one letter in common with a particular word (Kutas & Federmeier, 2011). For example, the orthographic neighborhood of the word “sleep” would include “sheep,” “sweep,” “sleek,” and “sleet.” Laszlo and Federmeier (2011) and Müller, Duñabeitia, and Carreiras (2010) found that N400 amplitudes were affected by orthographic neighborhood size. For example, Laszlo and Federmeier (2011) had participants view a series of words, pseudowords, illegal strings, and illegal acronyms; and press a button when they saw a “common English proper full name.” They found that N400 amplitude was greater for stimuli with larger orthographic neighborhoods. They suggested that when reading a string of letters, the semantic representations of the stimuli as well as its orthographic neighbors are activated.

With this research in mind, the original stimuli were optimized. A subset of stimuli, for which there were no significant differences between lexical properties of shared translation pairs and matched pairs, was created with the help of stimulus optimization software (Armstrong, Watson & Plaut, 2012). After optimization of stimuli, a second wave of data was collected and the larger data set was re-analyzed.

We predicted that, in the larger dataset, shared translation pairs would affect N400 amplitude in bilinguals but not monolinguals, indicating semantic integration of languages. Based on previous research, we expected bilinguals to generate smaller N400 amplitudes for shared translation pairs than matched pairs, reflecting a facilitative relationship. We also expected this relationship to be bidirectional, such that L1 would influence L2 semantic associations and L2 would influence L1 semantic associations. We predicted that level of semantic relatedness would affect N400 amplitude because this would be in accordance with previous ERP research as well as Degani et al.'s (2011) findings on the effect of relatedness on shared translation pairs. These findings, if observed, would support the current bilingual processing models of integrated lexicons at the semantic level. Due to the nature of the study and findings, we focus this paper on examining the facilitative vs. inhibitory relationship and semantic vs. lexical relationship.

2.0 METHODS

2.1 PARTICIPANTS

Fourteen monolingual English speakers, five Spanish-English bilinguals, and four English-Spanish bilinguals participated in the first wave of data collection. An additional eight Spanish-English bilinguals and one English-Spanish bilingual participated in the second wave of data collection. Participants were recruited in the University of Pittsburgh and Pennsylvania State University areas using e-mail. Out of the overall 32 participants, 16 were female and 16 were male. Bilinguals were highly proficient in both languages (see Table 1).

Table 1: Characteristics of the English-Spanish and Spanish-English Bilinguals as a function of wave of data collection

Note: Proficiency scores are averages of self-rated reading, writing, conversational, and speech comprehension proficiency on a 10 point scale, 1 indicating the lowest proficiency.

	Monolinguals	English-Spanish Bilinguals – Wave 1	Spanish-English Bilinguals – Wave 1	English-Spanish Bilinguals – Wave 2	Spanish-English Bilinguals – Wave 2
Age Began Learning L2	N/A	11.67 (5.13)	8.20 (3.56)	0 (0)	8.71 (3.64)
Time Spent Studying L2 (years)	N/A	7.33 (5.03)	14.60 (8.08)	18 (0)	18.42 (7.68)
Time Spent Immersed in L2 (years)	N/A	.81 (1.03)	8.40 (4.16)	18 (0)	4.57 (5.18)
L1 proficiency	9.85 (.39)	9.50 (.87)	9.55 (.76)	9.75 (0)	9.88 (.27)
L2 proficiency	N/A	9.00 (.25)	9.00 (1.16)	9.75 (0)	9.09 (.88)
Age (years)	18.42 (.67)	23.33 (4.93)	30.40 (10.69)	18 (0)	28.38 (4.24)

2.2 DESIGN

A 2 (linguistic background group: monolinguals, bilingual) x 2 (translation status: shared, matched) x 3 (relatedness level: highly related, moderately related, unrelated) design with an English block and Spanish block was used. Only data from the English block were analyzed.

2.3 STIMULI

60 matched, 120 different translation, and 120 shared translation word pairs were created using a norming study (Degani, 2011). In the shared translation pairs, the first word shown was

considered the “prime” and the second word shown was the “target.” Different translation pairs and matched pairs both functioned as control stimuli. In different translation pairs, the target was the same as the shared translation pairs’ targets but the prime was different. In matched translation pairs, both the prime and target were different from the shared translation pairs’ prime and target. In the English block, the matched words and shared translation words were matched on all significant variables including word length, concreteness, and frequency. The different words were not matched to the shared translation words on these variables. Thus, analysis of the English block focused on shared translation pairs and matched pairs, rather than different pairs. Examples of the English block stimuli are shown in Table 2. In the Spanish block, it was not possible to control for these variables for the matched and shared conditions.

Table 2: Examples of English block LDT stimuli as a function of relatedness level and translation status

Relatedness Level	Shared Translation Prime-Target	Different Translation Prime-Target	Matched Prime-Target
Highly Related	Jump-Leap	Dive-Leap	Dignity-Honor
Moderately Related	Sarcasm-Irony	Crudity-Irony	Belief-Religion
Unrelated	Wrist-Doll	Twist-Doll	Apple-Garbage

Two versions of word sets (with 60 matched, 60 different, and 60 shared pairs) were created for both the English and Spanish blocks so that the target word present in the different condition and shared condition could be separated and repetition of stimuli could be avoided. In each English version and the Spanish block, each condition consisted of 20 highly related, 20 moderately related, 20 unrelated pairs, 60 filler pairs, and 240 nonword pairs. Level of relatedness was determined by a norming study in which participants rated semantic relatedness of prime-target pair (Degani, unpublished data). Version was randomly assigned to each participant so that half the participants saw Version 1 and half Version 2.

2.4 STIMULUS OPTIMIZATION

To better match the shared and matched conditions, variables of all of the word pairs were obtained from the Machine Readable Dictionary (MRC) Psycholoinguistic Database (Wilson, 1988) and the English Lexicon Project (Balota, Yap, Cortese, Hutchison, Kessler, Loftis, Neely, Nelson, Simpson & Treiman, 2007) databases. Stochastic Optimization of Stimuli (SOS!) (Armstrong, Watson & Plaut, 2012) of the shared translation and matched word sets was used to generate a subset of words for which the two conditions were not significantly different for any of the above variables. Statistical analysis of the new word sets showed that shared translations and matched pairs were not significantly different in regards to number of letters (p=.546), number of syllables (p=.507), number of orthographic neighbors (p=.218), orthographic neighborhood frequency (p=.202) number of phonological neighbors (p=.184), word frequency (p=.976), bigram sum (p=.453), bigram mean (p=.176), bigram frequency by position (p=.544), and average bigram frequency (p=.544). The original and optimized English block shared translation and matched stimuli are shown in Appendix A. Both the first wave and second wave participants performed the LDT that included the same, original set of stimuli. However, re-analysis of the first wave data and analysis of the larger dataset only included ERP data generated from the optimized set of stimuli.

2.5 PROCEDURE

Participants were seated in a sound attenuated, electrically shielded booth (Industrial Acoustics, Inc.) about 75 cm from a computer screen. Using E-Prime (Psychological Software Tools, Inc., 2000) participants performed an L1 or L2 LDT, L1 operation span task, and the remaining L1 or L2 LDT while ERPs were recorded (e.g., if the participant performed the L1 LDT first, then he/she performed the L2 LDT after the operation span task). Each participant was randomly assigned to perform the first LDT block in his or her L1 or L2. To make a lexical decision, the participant pressed "1" if they believed the target was not a word or "5" if they believed the target was a word. In the LDT, a fixation cross was shown for 200 ms, the prime was shown for 200 ms, followed by a blank screen for 200 ms, the target until the lexical decision was made or 3000 ms, and a blank screen for 800 ms before the next pair (intertrial break). Stimuli were presented in lowercase black size-36 Arial font on a white screen. Participants were instructed to respond as quickly and accurately as possible and to try to only blink during intertrial breaks.

In the operation span task, subjects participated in a practice set followed by 15 critical sets. In each set, participants were shown operations and words alternatingly. At the end of each set, the participant was asked to recall as many words as possible. There were three sets each of two, three, four, five, and six operations before asked to recall the words. In each set, a fixation point was shown for 1000 ms, the operation for 2500 ms, the word for 1250 ms, and white recall screen. Some participants recalled the words on paper, whereas other participants recalled the words into the computer before pressing "esc" to begin the next set.

After the ERP tasks, the participant performed an L2 picture naming task, Raven's task, L1 picture naming task, handedness questionnaire, language history questionnaire (Tokowicz, Michael, & Kroll, 2004) and vocabulary posttest. The number of words named correctly in the picture naming tasks, self-rated proficiencies in the language history questionnaires, and number of words known in the vocabulary posttests were used as measures of proficiency. Correlations between the various measures of proficiency are shown in Table 3.

Table 3: Correlations between measures of proficiency (picture naming task accuracy, self-rated language history questionnaire proficiency, and words known in the vocabulary posttest)

Note: *indicates *p* < .05 and **indicates *p* < .01

	1	**2**	**3**	**4**
1. L1 Proficiency	-	-.28	.50*	-.43
2. L2 Proficiency	-.28	-	-.54*	.78**
3. L1 Picture Naming	.50*	-.54*	-	-.62*
4. L2 Picture Naming	-.43	.78**	-.62*	-

2.6 ELECTROENCEPHALOGRAM (EEG) RECORDING

EEG was recorded from 64 sites on the scalp as well as 6 sites on the face (mastoids, horizontal eyes, and vertical eyes). Scalp electrodes were mounted in an electrode cap (QuickCap). Electrode impedance was kept below 5 kΩ. Electrodes were re-referenced to the average left and right mastoids. An ocular artifact reduction transformation was performed to eliminate noise resulting from blinks. Segments from 100 ms before to 1000 ms after stimulus onset were extracted, baseline corrected, and low pass filtered at 30 Hz using Neuroscan. Trials with values 75μV above or below baseline were then rejected using Neuroscan. Each trial was also visually inspected for further rejection. Trials for each word type (e.g. shared unrelated or matched highly related) were averaged for each individual. From these averages, the mean amplitude during 300 to 500 ms for the channels F3, F3, FZ, F4, C3, CZ, C4, P3, PZ, P4 were extracted.

3.0 RESULTS

3.1 BEHAVIORAL DATA

English LDT accuracy and mean reaction times for the larger dataset were analyzed using repeated-measures Analyses of Variance (ANOVAs). Accuracy was the percentage of trials a participant correctly determined whether or not a stimulus was a word. Mean reaction time was the average amount of time it took a participant to make a lexical decision (in trials in which the correct decision was made) after the target stimulus was shown. An ANOVA was conducted using linguistic background group, translation status, relatedness level, and mean reaction time. The ANOVA showed a significant effect of relatedness level on mean reaction time (F (2, 56) = 5.085, MSE = 2688 p = .009, η_p^2 = .154) such that mean reaction time was lowest for highly related pairs and highest for unrelated pairs. Mean reaction times are shown in Figure 1. Another ANOVA was conducted using linguistic background group, translation status, relatedness level, and accuracy. The ANOVA also showed a significant effect of translation status on accuracy time (F (1, 28) = 9.022, MSE = 0, p = .006, η_p^2 = .244) such that mean accuracy was lower for shared translation pairs than matched pairs. Mean accuracies are shown in Figure 2. No other significant effects were found.

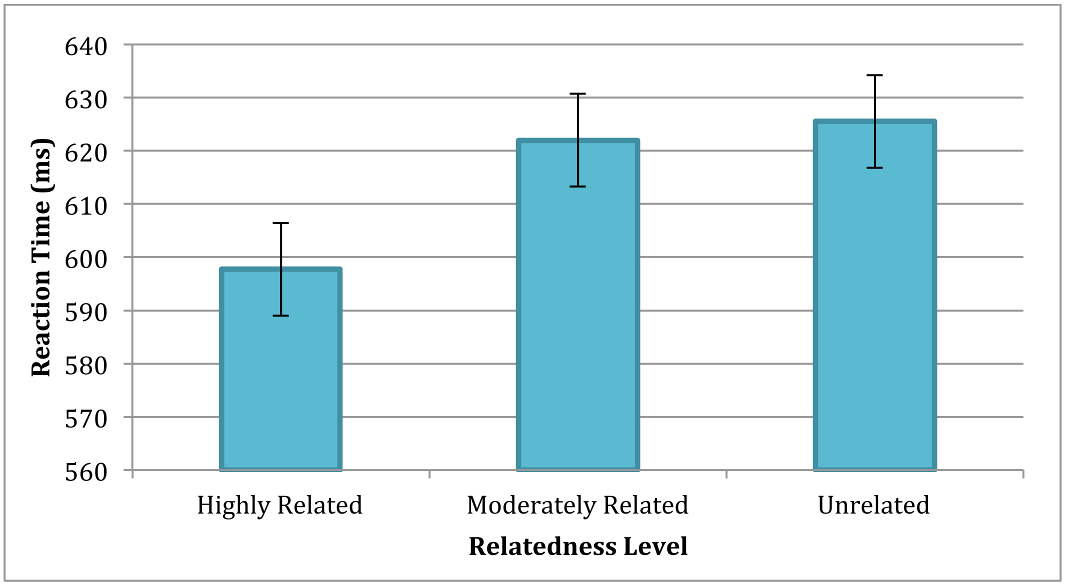

Figure 1: Mean reaction times to make correct lexical decision after presentation of target stimulus for larger dataset participants as a function of relatedness level

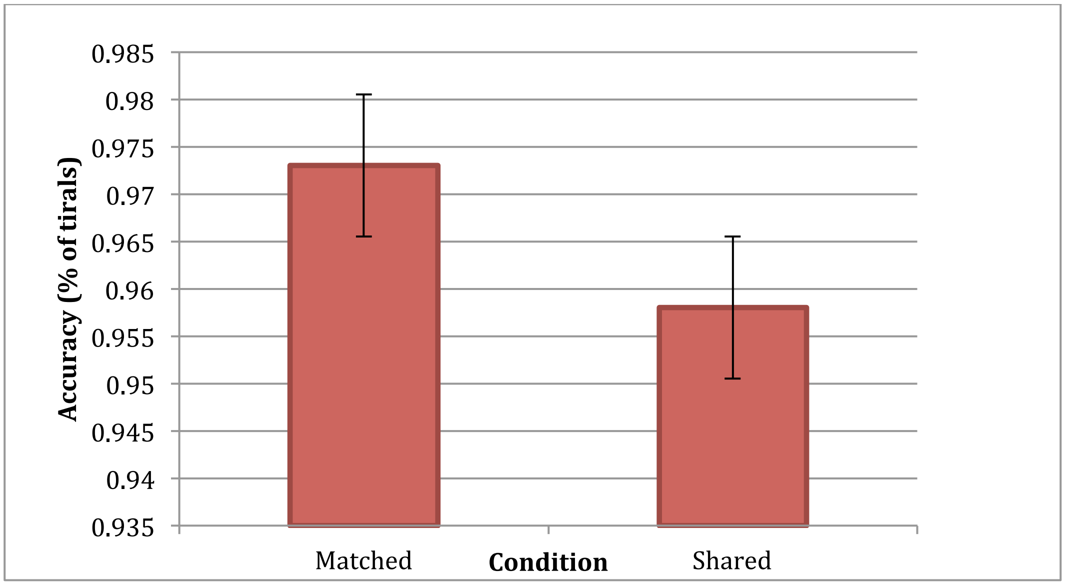

Figure 2: Mean accuracy in lexical decision task larger dataset participants as a function of translation status

3.2 ERP DATA

A subset of ERP waveforms for the first wave participants is shown in Figure 3. A subset of ERP waveforms for the second wave participants is shown in Figure 4.

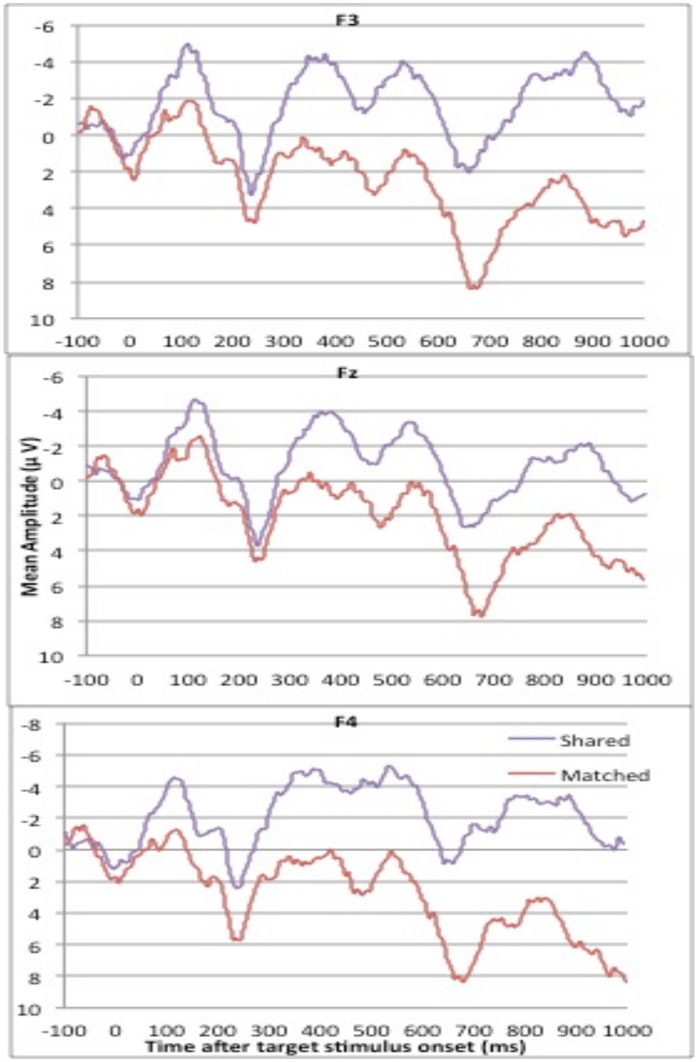

Figure 3: F electrode ERP waveforms generated by first wave bilinguals for matched (unrelated and related) pairs and shared translation (unrelated and related) pairs in English lexical decision task

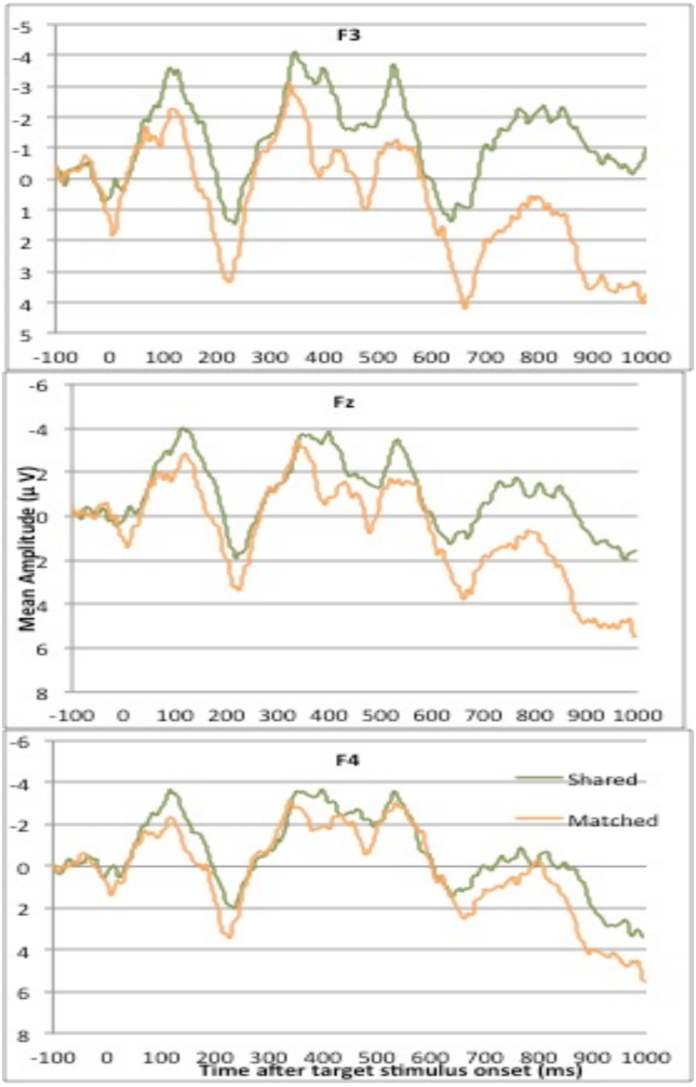

Figure 4: F electrode ERP waveforms generated by larger dataset bilinguals for unrelated matched pairs and unrelated shared translation pairs in English lexical decision task

ERP mean amplitudes in the N400 time window (300 to 500ms) for the first wave of data and the larger dataset were both analyzed. ERP data from nine electrodes were used. The nine electrodes were F3, C3, P3, FZ, CZ, PZ, F4, C4, and P4. F (frontal), P (parietal), and C (central) allowed for comparisons between lobes. 3 (left), Z (midline), and 4 (right) allowed for comparisons in laterality. An ANOVA of the first wave of data was conducted using linguistic background group, translation status, relatedness level, lobe, and laterality. Moderately related pairs were not included in the ANOVA to allow for more interpretable interactions. Mean N400 amplitudes as a function of linguistic background group, translation status, and relatedness level are shown in Figure 5. Main effects of lobes or laterality are not of theoretical interest and therefore are not reported.

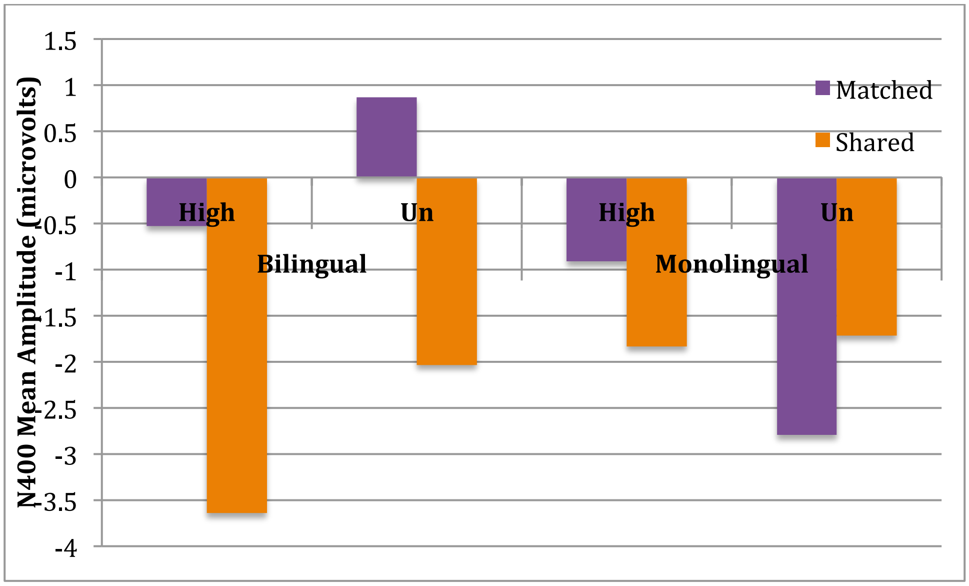

Figure 5: Mean N400 amplitudes as a function of linguistic background group, and relatedness level for larger dataset in first wave participants

The ANOVA of the first wave of data showed a significant interaction between translation status and linguistic background group (F (1, 21) = 4.416, MSE = 106.1, p = .048, η_p^2

= .174). Bilinguals showed more negative N400 mean amplitudes for shared translation pairs than matched pairs, whereas monolinguals did not. These results are shown in Figures 6 and 7. No other significant interactions were found for the first wave of data.

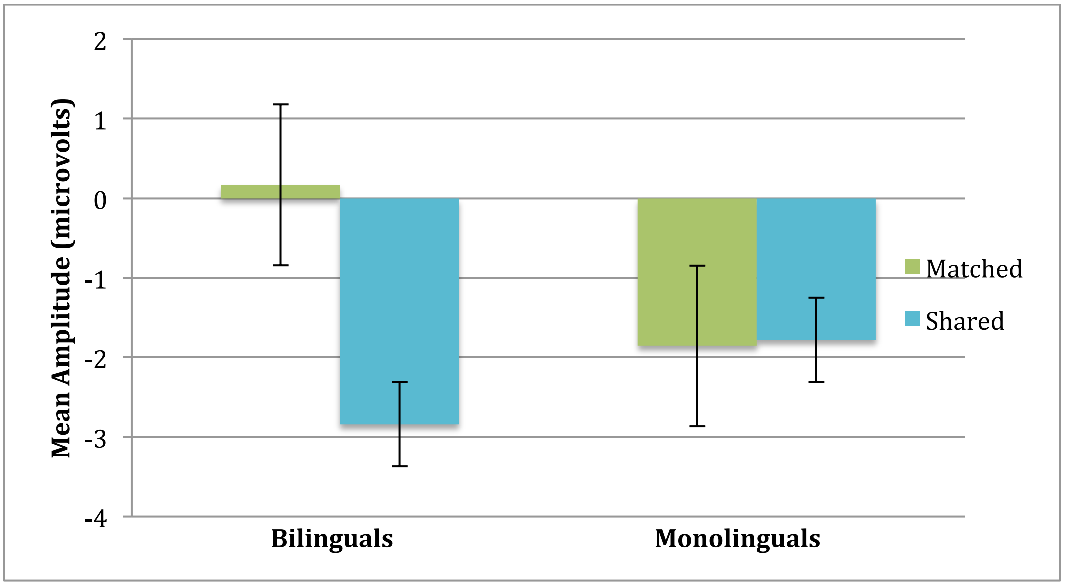

Figure 6: Mean N400 Amplitudes for Matched and Shared Translation Pairs in First Wave Monolinguals and Bilinguals

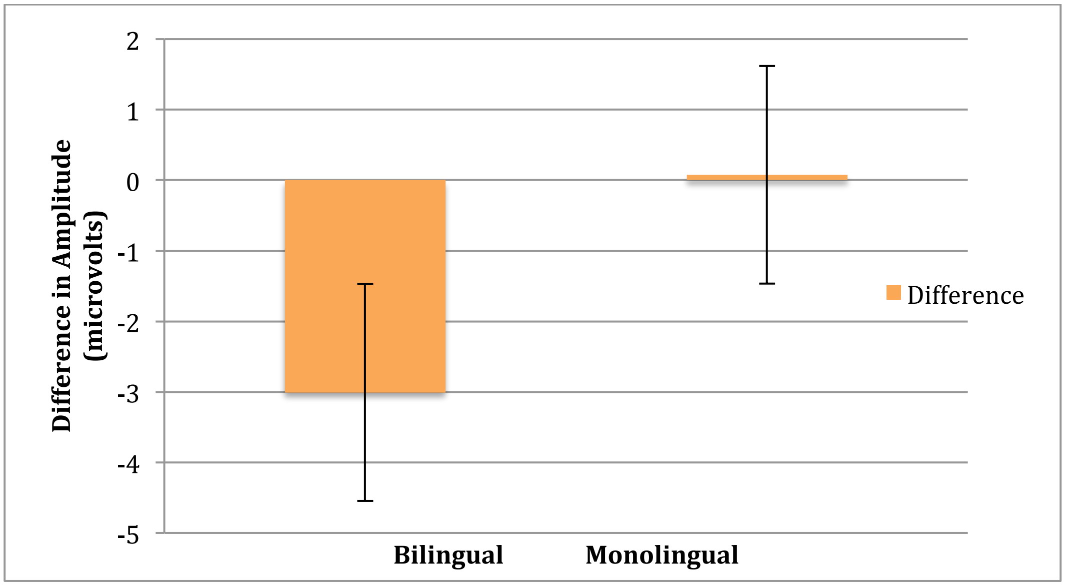

Figure 7: Difference between Matched and Shared mean N400 amplitudes in First Wave Monolinguals and Bilinguals

An ANOVA of the larger dataset was conducted using linguistic background, translation status, relatedness level, lobe, and laterality. Moderately related pairs were not included in the ANOVA to allow for more interpretable interactions. Mean N400 amplitudes as a function of linguistic background group, and relatedness level are shown in Figure 8.

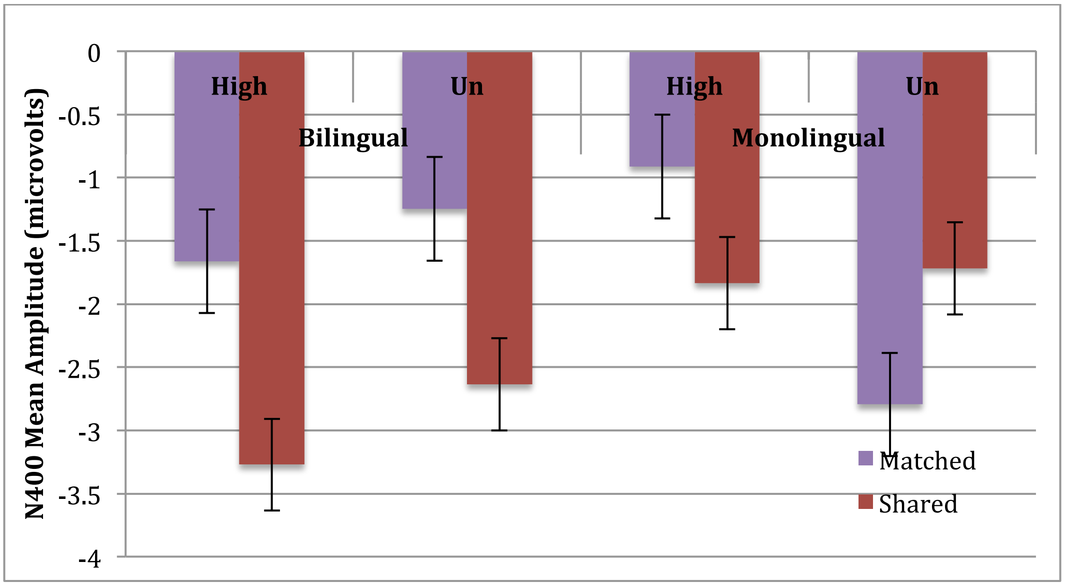

Figure 8: Mean N400 amplitudes as a function of linguistic background group, and relatedness level for larger dataset

The ANOVA showed a significant three-way interaction between translation status, and relatedness level (*F* (2, 60) = 4.679, *MSE* = 52.484 *p* = .013, η_p^2 = .135). To further probe the data, a *t*-test was run between matched and shared mean N400 amplitude for the different lobes and relatedness levels. The *t*-test showed a marginally significant difference between matched and shared translation pairs' ERP amplitudes for related pairs across the frontal lobe (*p* = .052, Bonferroni significance level = .008). The mean amplitudes as a function of relatedness level and lobe from the larger dataset are shown in Figure 9. No other significant effects were shown. An Analysis of Covariance (ANCOVA) using operation span performance as a covariate and linguistic background group, translation status, relatedness level, lobe, and laterality did not show any significant effects.

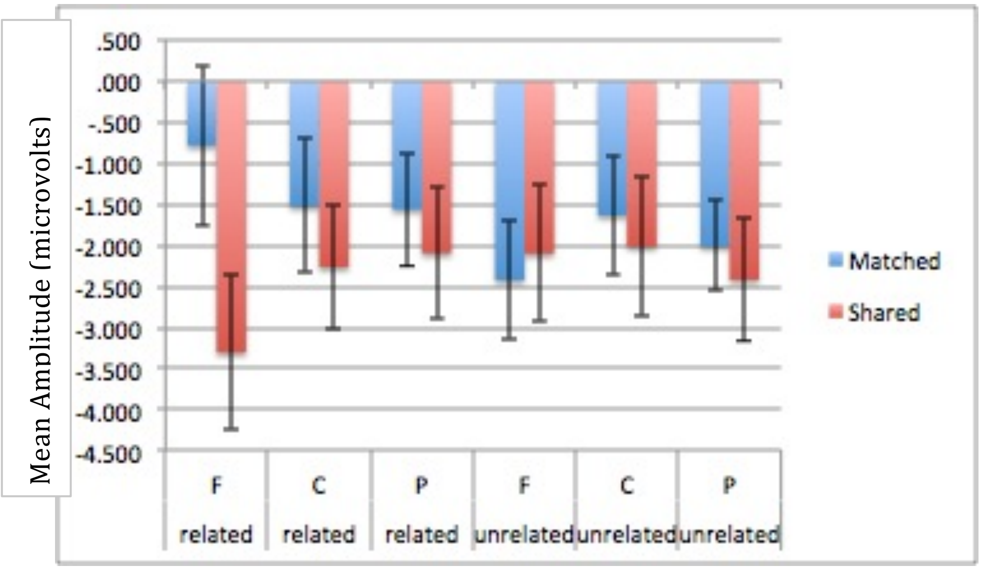

Figure 9: Mean N400 Amplitude for Matched and Shared Translation Pairs in Larger Dataset

4.0 DISCUSSION

In this study, we investigated the relationship between Spanish-English shared translation pairs of different relatedness levels using ERP N400 mean amplitudes. Analysis of the first wave ERP data indicated that bilinguals generate significantly larger mean N400 amplitudes for shared translation pairs than matched pairs, whereas monolinguals do not. However, analysis of the larger dataset behavioral measures and ERP data did not demonstrate an interaction between linguistic background and translation type.

The first wave N400 data suggest that there is a relationship between translation status and linguistic background group. For bilinguals, mean N400 amplitude was larger for shared translation pairs than matched pairs. Because larger N400 amplitudes are indicative of an inhibitory connection, this suggests shared translation pairs have an inhibitory relationship. Furthermore, because this relationship was revealed by N400 amplitudes, this may be reflective of a semantic link between shared translation pairs. This suggests that activation of one shared translation ("wrist") inhibits the semantic representation of the other translation ("doll"). Such an inhibitory connection would be beneficial in differentiating when to use each translation. For example, "watch" and "clock" both translate to "reloj" in Spanish. In English, the two words are used in separate contexts. Inhibition of one translation's mental representation while the other translation's representation is activated would prevent the inappropriate word from being used (Degani et al., 2011). Thus, these results are inconsistent with Degani et al.'s (2011) findings that shared translation pairs have a facilitative relationship. Furthermore, the lack of an interaction with relatedness level suggests the inhibitory relationship exists for highly related and unrelated pairs. Lastly, because the bilingual group included both English-Spanish and Spanish-English bilinguals, we speculate that this inhibitory relationship is bidirectional; not only does L1 influence L2 processing, but L2 influences L1 processing. However, because our sample size was not large enough to analyze English-Spanish and Spanish-English bilinguals separately, no strong conclusions can be drawn about the bidirectional nature of the relationship.

Monolinguals did not generate N400s with significantly different amplitudes for shared translation pairs than matched pairs. This indicates lexical properties that can influence N400 amplitude were controlled for. Thus, the effect on N400 amplitude in bilinguals must be due to the relationship between shared translation pairs, which can only occur if there is influence of the Spanish word ("muñeca") on processing of the English words ("wrist" and "doll"). This is indicative of an interaction between L1 and L2 processing.

The inhibitory connection demonstrated by first wave ERP data was not supported by behavioral and ERP analysis of the larger dataset. Analyses of behavioral data showed lower mean response times for highly related pairs and higher mean response times for unrelated pairs. These results are consistent with the priming effect, in which processing of a word is facilitated by being preceded by a semantically related word (Kutas et al., 2000). Because shared translation words and matched words were matched on several lexical properties, it is unclear why accuracy was lower for shared translation pairs than matched pairs. One explanation is that there were differences between shared translation words and matched words in regards to lexical properties for which there was not sufficient data. As a result, it was not possible to match the matched and shared translation words on these lexical properties using statistical analyses or optimization software. However, because there was no interaction between linguistic background group and translation status for response time, the behavioral data do not indicate that bilinguals process shared translation pairs differently than matched pairs. Thus, no conclusions on the relationship between shared translation pairs can be drawn from the behavioral data analyses.

ERP analysis of the larger dataset also showed no significant interaction between linguistic background group and translation status. Similar to the behavioral analysis, this suggests that bilinguals do not process shared translation pairs differently than matched pairs, at least at the semantic level. The main effect in analysis of the larger dataset was an interaction between translation status, lobe, and relatedness. More specifically, both bilinguals and monolinguals generated larger N400 amplitudes for highly related shared translation pairs than highly related matched pairs over the frontal lobe. One possible explanation for the lack of an interaction between linguistic background group is that bilinguals may have been generating N400s with different mean amplitudes for shared translation pairs in comparison to monolinguals, but the difference was not significant.

It is difficult to explain why the addition of second wave participants eliminated the interaction between linguistic background group and translation status. The main differences between the two waves of participants were average L1, Spanish, and English proficiencies based on language history questionnaires. To better understand the relationship between proficiency and difference in N400 amplitudes between matched and shared translation pairs, a correlation was ran. This revealed a significant negative correlation ($r = -.643$, $p < .01$) between L1 proficiency and the difference between matched and shared translation N400 amplitudes. This meant that the higher a bilingual participant's L1 proficiency was, the smaller the difference between shared translation and matched pairs N400 amplitude. Because the second wave participants had a slightly higher average L1 proficiency (9.861 ± .253) than first wave participants (9.531 ± .737), it is possible that differences in proficiency contributed to the inconsistency between first wave and larger dataset results. Furthermore, the difference between L1 and L2 proficiency for first wave participants (.55 ± 1.534) was slightly lower than for second wave participants (.781 ± 1.039). This suggests that first wave participants were better balanced than second wave participants in terms of L1 and L2 proficiencies; second wave participants tended to be more L1 dominant.

In a study, Elston-Güttler (2005) explored the effect of L2 proficiency on processing of German-English shared translation pairs. The authors found that bilinguals with low L2 proficiencies generated different N200 amplitudes for shared translation pairs than pairs that did not share a translation. They also found that bilinguals with high L2 proficiencies did not show N200 ERP modulations for shared translation pairs. Elston-Güttler suggested that lower proficiency bilinguals have stronger L1-L2 connections at the orthographic/word form level. Furthermore, in a number of studies, Kroll and Curley (1988, as cited in de Groot & van Hell, 2005) suggested that bilinguals with higher L2 proficiencies process language using concept mediation, whereas bilinguals with low L2 proficiencies use word association links. This means that highly proficient bilinguals are more likely to process the lexical representation of a word in one language to the concept, and then from the concept to the word in the other language. Less proficient bilinguals translate the lexical representation of a word in one language directly to the lexical representation in the other language.

It is therefore possible that the bilinguals with strong L1 dominances (second wave participants) process language similar to bilinguals with low L2 proficiencies. Both types of bilinguals would have relatively large imbalances between L1 and L2 proficiencies. Thus, the second wave participants may have had stronger links between the L1 and L2 lexical representations and were using word association links. As a result, the access to semantic representations during the LDT may have been reduced. Because the N400 amplitude is thought to reflect semantic processing, this lack of semantic representation access, would explain why the second wave participants did not generate significantly different N400 amplitudes for shared translation pairs than matched pairs. On the other hand, linguistically balanced bilinguals (first wave participants) may have had weaker links between L1 and L2 lexical representations and relied more on concept mediation. During the LDT, these participants may have accessed semantic representations more heavily. This allowed for differences between shared translation pair and matched pair processing in these bilinguals to be reflected in N400 amplitude.

This explanation would be more consistent with the Revised Hierarchical Model than the BIA Model because it accounts for proficiency dependent changes in integration between L1 and L2 semantic representations. The Revised Hierarchical Model assumes that L1 words are more strongly connected to concepts than are L2 words. As a result, L2 words are assumed to be connected strongly to the L1 translation equivalents, rather than to the concepts. As a bilingual learns an L2, he/she utilizes the L2 to L1 translation to access concepts, thereby leading to feedback that strengthens the L2 to L1 lexical link. Furthermore, as a bilingual becomes more proficient in the L2, he/she will begin to strengthen the direct links between L2 words and concepts (Dijkstra, 2005). If a bilingual is highly proficient in L1, the links between L1 words and concepts may be stronger. It may be more advantageous for such bilinguals to use the L2 to L1 lexical link to access concepts. As a result, lexical links between the two languages may strengthen more than the direct links between the L2 word and concept. Thus, the second wave participants, who consisted mainly of Spanish-English bilinguals, may not have had strong links between the L2 English LDT stimuli and concepts. Perhaps the semantic integration between L1 and L2 assumed by the BIA+ model depends on the balance between L1 and L2 proficiencies.

In addition, the collection of the two waves of data at different times may have contributed to the variation in results. Whereas experimental design for the second wave of data collection replicated first wave design as closely as possible, there may have been minor differences in experimental materials or participant backgrounds that could not be controlled for.

To summarize, the first wave findings indicate an inhibitory connection between shared translation pairs that is at the semantic level and independent of level of relatedness for bilinguals. They also suggest that this relationship is bidirectional, but due to the small sample size, this cannot be considered conclusive evidence. The larger dataset findings do not indicate that a relationship exists between shared translation pairs for bilinguals at the semantic level. We suggest the inconsistency between these findings is a result of differences in bilinguals' proficiencies.

5.0 CONCLUSION

This study built on Degani et al.'s (2011) study to further examine the facilitative relationship between shared translation pairs, the effect of level of relatedness, and the bidirectional influence of L1 and L2 processing at the semantic level. N400 results from the first wave of participants did not provide support for a facilitative relationship, but rather an inhibitory relationship between shared translation pairs at the semantic level. However, the results did support Degani et al.'s (2011) findings that this relationship is independent of relatedness level and may be bidirectional. N400 and behavioral data from the larger dataset did not provide support for a semantic relationship between shared translation pairs. However, ERP results did reveal a three-way interaction between lobe, relatedness level, and translation status. The inconsistencies between the two results suggested that semantic integration may depend on the balance between L1 and L2 proficiencies. More specifically, a high L1 proficiency (in relation to L2) is correlated with a smaller semantic inhibitory relationship. Thus, these findings support a bidirectional, relatedness level independent, semantic inhibitory relationship between shared translation pairs for highly proficient bilinguals with similar L1 and L2 proficiencies. Lastly, the findings support semantic L1-L2 integration for highly proficient bilinguals who have similar L1 and L2 proficiencies.

REFERENCES

Armstrong, B., Watson, C., & Plaut, D. (2012). SOS! An Algorithm and software for the stochastic optimization of stimuli. *Behavior Research Methods, 3,* 675-705. doi: 10.3758/s13428-011-0182-9

Balota, D.A., Yap, M.J., Cortese, M.J., Hutchison, K.A., Kessler, B., Loftis, B., Neely, J.H., & Nelson, D.L., Simpson, G.B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods*, 39, 445-459.

Conway, A., Kane, M., Bunting, M., Hambrick, Z., Wilhelm, O., & Engle, R. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review, 12*(5), 769-786. Retrieved from http://link.springer.com/article/10.3758%2FBF03196772

Degani, T. (2011). Bidirectional transfer: Consequences of translation ambiguity for bilingual word meaning. Unpublished doctoral dissertation, University of Pittsburgh, PA.

Degani, T. (N.D.) Unpublished data.

Degani, T., Prior, A., & Tokowicz, N. (2011). Bidirectional transfer: The effect of sharing a translation. *Journal of Cognitive Psychology, 23,* 18-28. doi:10.1080/20445911.2011.445986

Degani, T., & Tokowicz, N. (2010). Semantic ambiguity within and across languages: An integrative review. *The Quarterly Journal of Experimental Psychology, 63*(7), 1266-1303. doi: 10.1080/17470210903377372

de Groot, A., van Hell, J. (2005). The Learning of Foreign Language Vocabulary. Kroll, J.F., & de Groot, A. (Eds.) In Handbook of Bilingualism: Pscyholinguistic approaches. Retrieved from http://www.researchgate.net/profile/Annette_Groot/publication/254870813_The_learning_of_foreign_language_vocabulary/links/5412e1f00cf2bb7347db10ca.pdf#page=546

Dijkstra, T (2005). Bilingual Visual Word Recognition and Lexical Access. Kroll, J.F., & de Groot, A. (Eds.) In *Handbook of Bilingualism: Pscyholinguistic approaches.* Retrieved from http://www.researchgate.net/profile/Annette_Groot/publication/254870813_The_learning_of_foreign_language_vocabulary/links/5412e1f00cf2bb7347db10ca.pdf#page=546

Duñabeitia, J., Perea, M., & Carreiras, M. (2010). Masked Translation Priming Effects With Highly Proficient Simultaneous Bilinguals. *Experimental Psychology, 57*(2), 98-107. doi: 10.1027/1618-3169/a000013

Elston-Güttler, K., Paulmann, S., & Kotz, S.A. (2005). Who's in Control? Proficiency and L1 Influence on L2 Processing. *Journal of Cognitive Neuroscience, 17,* 1593-1610. D

Jiang, N. (2002). Form-meaning mapping in vocabulary acquisition in a second language. *SSLA, 24*, 617-637. doi:10.1371/journal.pone.0054402

Jiang, N. (2004). Semantic transfer and its implications for vocabulary teaching in a second language. Modern Language Journal, 88, 416□432. doi:10.1111/j.0026-7902.2004.00238

Kerkhofs, R., Dijkstra, T., Chwilla, D., & Bruijn, E. (2006). Testing a model for bilingual semantic priming with interlingual homographs: RT and N400 effects. *Brain Research, 1068*, 170-183. doi:10.1016/j.brainres.2005.10.087

Kroll, J., Bobb, S., & Hoshino, N. (2014). Two Languages in Mind: Bilingualism as a Tool to Investigate Language, Cognition, and the Brain. *Association for Psychological Science, 23*(3), 159-163. doi: 10.1177/0963721414528511

Kutas, M., & Federmeier, K. (2009). N400. *Scholarpedia, 4,* 7790. doi:10.4249/scholarpedia.7790

Kutas, M., & Federmeier, K. (2011). Thirty years and counting: Finding meaning in the N400 component of the event related brain potential (ERP). *Annual Review of Psychology, 62,* 621-647. doi:10.1146/annurev.psych.093008.131123

Kutas, M., Federmeier, K.D., Coulson, S.C., King, J.W., & Muente, T.F. (2000). Language. In *Handbook of Psychophysiology* (576-601). Cambridge: Cambridge University Press. Retrieved from http://psychology.uchicago.edu/people/faculty/cacioppo/jtcreprints/ctb00.pdf

Laszlo, S., & Federmeier, K. (2011). The N400 as a snapshot of interactive processing: Evidence from regression analyses of orthographic neighbor and lexical associate effects. *Psychophysiology, 48*, 176-186. doi: 10.1111/j.1469-8986.2010.01058.x

Marian, V., & Spivey, M. (2003). Competing activation in bilingual language processing: Within-and between-language competition. *Bilingualism: Language and Cognition, 6*(2), 97-115. doi: 10.1017/S1366728903001068

Müller, O., Duñabeitia, J., & Carreiras, M. (2010). Orthographic and associative neighborhood density effects: What is shared, what is different? *Psychophysiology, 47*, 455-466. doi: 10.1111/j.1469-8986.2009.00960.x

Murre, J. (2005). Models of Monolingual and Bilingual Language Acquisition. Kroll, J.F., & de Groot, A. (Eds.) In Handbook of Bilingualism: Pscyholinguistic approaches. Retrieved from http://www.researchgate.net/profile/Annette_Groot/publication/254870813_The_learning_of_foreign_language_vocabulary/links/5412e1f00cf2bb7347db10ca.pdf#page=546

Pavlenko, A. & Malt, B. (2011). Kitchen Russian: Cross-linguistic differences and first-language object naming by Russian-English bilinguals." *Bilingualism: Language and Cognition, 14*(1), 19-45. doi: 10.1017/S136672891000026X

Perrin, F., & García-Larrea, L. (2003). Modulation of the N400 potential during auditory phonological/semantic interaction. *Cognitive Brain Research, 17,* 36-47. doi:10.1016/S0926-6410(03)00078-8

Prior, A. and Gollan, T. (2011). Good Language-Switchers are Good Task-Switchers: Evidence from Spanish–English and Mandarin–English Bilinguals. Journal of the International Neuropsychological Society, 17, pp 682-691. doi:10.1017/S1355617711000580.

Prior, A., & MacWhinney, B., & Kroll, J. F. (2007). Translation norms for English and Spanish: The role of lexical variables, word class, and L2 proficiency in negotiating translation ambiguity. *Behavior Research Methods, 39,* 1029-1038. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4109968/

Psychological Software Tools, Inc. (2000). *E-Prime* [Computer software]. Pittsburgh, Pa: Psychological Software Tools, Inc.

Sanbonmatsu, D., Strayer, D., Medeiros-Ward, N., & Watson, J. (2013). Who Multi-Tasks and Why? Multi-Tasking Ability Perceiveed Multi-Tasking Ability, Impulsivity, and Sensation Seeking. *PLoS One, 8*(1), 1-8. doi:10.1371/journal.pone.0054402

Sur, S., & Sinha, V.K. (2009). Event-related potential: An overview. *Industrial Psychiatry Journal, 18,* 70-73. doi: 10.4103/0972-6748.57865

Thierry, G., & Wu, Y.J. (2007). Brain potentials reveal unconscious translation during foreign-language comprehension. *Proceedings of the National Academy of Sciences, 104,* 12530-12535. doi: 10.1073/pnas.0609927104

Thomas, M., & van Heuven, W. (2005). Computational Models of Bilingual Comprehension. Kroll, J.F., & de Groot, A. (Eds.) In *Handbook of Bilingualism: Pscyholinguistic approaches.* Retrieved from http://www.researchgate.net/profile/Annette_Groot/publication/254870813_The_learning_of_foreign_language_vocabulary/links/5412e1f00cf2bb7347db10ca.pdf#page=546

Tokowicz, N., Michael, E. B., & Kroll, J. F. (2004). The roles of study-abroad experience and working-memory capacity in the types of errors made during translation. *Bilingualism: Language and Cognition, 7*(3), 255-272. doi: 10.1017/S0142716408090048

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127-154. doi:10.1016/0749-596X(89)90040-5

Wilson, M. D. (1988). The MRC psycholinguistic database: Machine readable dictionary, version 2. Behavior Research Methods Instruments and Computers, 20, 611.

Youn, H., Sutton, L., Smith, E., Moore, C., Wilkins, J., Maddieson, I., Croft, W., Bhattacharya, T. (2015). On the universal structure of human lexical semantics. *PNAS,* 1-6. doi: 10.1073/pnas.1520752113

APPENDIX A

ENGLISH BLOCK MATCHED AND SHARE TRANSLATION PAIRS

Table 4: English block matched prime-target pairs for lexical decision task

Note: *indicates stimuli not included in optimized subset

Highly Related		Moderately Related		Unrelated	
Prime	Target	Prime	Target	Prime	Target
pleasant	nice	borrow	ask	anticipate*	look*
noisy	loud	hinge*	axis*	officer	town
grasp	hold	siren	horn	reading	shot
sun	star	sperm	seed	share	drop
audience	crowd	poem	song	vote	area
obstruct	block	necklace*	chain*	job	feet
dignity	honor	laugh	smile	ray*	fund*
step	stair	clean	shiny	criticize*	visit*
authority*	expert*	apology	regret	hammer	screw
avoid	ignore	check	result	rash	dance
occur	appear	department	college	style*	credit*
hear*	listen*	flee	smuggle	baby*	powder*
organize	arrange	gain	fortune	accept	revenge
artist	painter	belief	religion	apple	garbage
glad*	pleased*	cart*	stroller*	shore	balcony
future*	tomorrow*	doubt	suspicion	judge	display
machine*	equipment*	volunteer	contribute	teacher	gardener
benefit	advantage	objection	resistance	telegram	lightning
decision	conclusion	theory*	hypothesis*	brother	fireplace
hero	protagonist	divide*	distribute*	crop	tumor

Table 5: English block, version 1 shared translation prime-target pairs for lexical decision task

Note: *indicates stimuli not included in optimized subset

Highly Related			Moderately Related			Unrelated		
Target	Prime	Translation	Target	Prime	Translation	Prime	Target	Translation
street*	road*	calle	proof*	test*	prueba	pope	potato	papa
boat*	ship*	bote	address	direction	dirección	flame	llama	llama
warmth*	heat*	calor	holiday	vacation	vacación	chamber	camera	cámara
chef	cook	cocinero	meat	flesh	carne	invert	invest	invertir
finding	discovery	descubrimiento	deny	negate	negar	wrist	doll	muñeca
talk*	speak*	hablar	judgment*	trial*	juicio	bank	bench	banco
balance	equilibrium	equilibrio	hour*	time*	hora	pile*	battery*	pila
award	prize	premio	voucher	ticket	boleto	career*	race*	carrera
necessity*	need*	necesidad	strength	force	fuerza	take	drink	tomar
tale	story	cuento	meal	food	comida	assistance	attendance	asistencia
pick*	choose*	escoger	duty*	obligation*	obligación	drive	manage	manejar
vehicle	automobile	vehículo	wish*	want*	desear	touch	play	tocar
rock	stone	piedra	point	period	punto	cape*	end*	cabo
film	movie	película	cause*	reason*	razón	bale*	bullet*	bala
rabbit	bunny	conejo	drill	exercise	ejercicio	plant	floor	planta
swear	curse	maldición	ability	competence	capacidad	cure	minister	cura
autumn*	fall*	otoño	title	degree	título	clue	path	pista
earth	world	mundo	sign*	announcement*	anuncio	talent	sir	don
danger	trouble	peligro	fabrication	invention	invento	agitation	excitement	excitación
quarrel	fight	pelea	wood	forest	bosque	attempt	intention	intento

Table 6: English block, version 2 shared translation prime-target pairs for lexical decision task

Note: *indicates stimuli not included in optimized subset

Highly Related			Moderately Related			Unrelated		
Target	Prime	Translation	Target	Prime	Translation	Prime	Target	Translation
blouse*	shirt*	camisa	drive*	conduct*	conducir	glue*	tail*	cola
relief	alleviation	alivio	tongue	language	lengua	sail*	candle*	vela
ceiling	roof	techo	guilt	fault	culpa	appointment	citation	cita
reject	refuse	denegar	dresser	closet	armario	peak*	beak*	pico
edge	border	borde	card	letter	carta	room	piece	pieza
draw	sketch	dibujar	trust	confidence	confianza	balloon	globe	globo
watch*	clock*	reloj	mark	brand	marca	deceive*	disappoint*	decepcionar
serpent	snake	serpiente	gather	join	juntar	cut	court	corte
plate	dish	plato	research	investigation	investigación	rob*	dock*	atracar
jump	leap	saltar	argument	discussion	discusión	duck	leg	pata
fate	destiny	destino	pity	shame	lástima	carry	charge	cargar
company	business	empresa	sarcasm	irony	sarcasmo	crest	cockscomb	cresta
army	military	ejército	sale	offer	oferta	writing*	deed*	escritura
answer	response	respuesta	cheer	toast	brindis	range	saw	sierra
talk*	chat*	charlar	coin	money	moneda	point	note	apuntar
seat	chair	silla	mind*	care*	importar	anger	cholera	cólera
help	assist	ayudar	wife*	woman*	mujer	treetop	goblet	copa
home	house	casa	luck*	chance*	suerte	notice	news	noticia
sofa	couch	sofá	transfer*	move*	trasladar	tent*	store*	tienda
hurt	harm	lastimar	balance	scale	balance	wear*	dress*	vestir