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Investigation of language impairment and treatment-induced recovery patterns between verbs and nouns in Mandarin-English bilinguals with aphasia

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INVESTIGATION OF LANGUAGE IMPAIRMENT AND TREATMENT-INDUCED RECOVERY PATTERNS BETWEEN VERBS AND NOUNS IN MANDARIN-ENGLISH BILINGUALS WITH APHASIA

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ABSTRACT

Previous research examining lexical-retrieval difficulty in bilinguals with aphasia (BWA) has identified a verb-noun dissociation in naming in both first (L1) and second (L2) languages, i.e., a lower naming accuracy for verbs than nouns. Yet, the evidence is limited to typologically similar languages, and whether the same patterns of lexical impairment emerge in other linguistic contexts (i.e., discourse) is unclear. Lexical-retrieval difficulty has been commonly targeted in bilingual aphasia rehabilitation, but mainly focused on nouns. Whether similar patterns of treatment-induced language recovery emerge in both noun and verb treatment remains unclear. Studies implementing semantic-based treatment have shown robust treatment gains, but patterns of generalizations are inconsistent. Most evidence in bilingual aphasia rehabilitation has come from individuals speaking Indo-European languages. Given that the Chinese-speaking population is rapidly growing nationwide, future research needs to establish the evidence base for aphasia rehabilitation in this population. Hence, two studies were undertaken in this dissertation work to address these critical issues.

In Study 1, twelve Mandarin-English BWA were administered a battery of standardized naming and discourse tasks in both languages. A verb-noun dissociation was found across languages in single-word naming and discourse production. The magnitude of this verb-noun dissociation was similar in L1 and L2 in naming but was significantly larger in L2 than in L1 in discourse, depending on the specific task. Findings indicated a direct relationship between naming and lexical retrieval in discourse irrespective of the target language.

In Study 2, the same group of Mandarin-English BWA underwent semantic-based treatment targeting noun and verb retrieval. These participants demonstrated improvement on the overall aphasia severity and lexical retrieval based on their performance on the standardized language assessments. Results from weekly naming probes showed a positive treatment gain in both noun and verb treatment, but to a greater extent in verb treatment. Generalization to semantically-related items was captured in noun treatment. Cross-language generalization was identified in both treatments, but to a larger extent when training verbs. Additionally, widespread generalizations beyond the single-word level and to untrained naming tasks were found following both noun and verb treatment. However, more generalizations were captured after noun treatment, particularly in discourse and untrained naming tasks. These two studies provided strong evidence of bilingual language impairment and treatment-induced language recovery between nouns and verbs in Mandarin-English BWA.

The general discussion reviews key findings from Studies 1 and 2 and discusses clinical implications for studying bilingual aphasia recovery and language rehabilitation in future work.

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LIST OF ABBREVIATIONS

ABC	Aphasia Battery in Chinese
AQ	Aphasia Quotient
ASPT	Argument Structure Production Test
BAT	Bilingual Aphasia Test
BNT	Boston Naming Test
BWA	Bilinguals with Aphasia
CH	Chinese
CIU	Correct Information Units
CLAN	Computerized Language ANalysis
CLMM	Cumulative Link Mixed-Effects Model
CLQT	Cognitive Linguistic Quick Test
C-QPA	Computerized Quantitative Production Analysis
CU	Complete Utterance
EF	Executive Function
EN	English
ES	Effect Size
GLMM	Generalized Mixed-Effects Models
IPNP	International Picture Naming Project
L1	First Language
L2	Second Language
L3	Third Language
L4	Forth Language
LAR	Language Ability Rating
LMM	Linear Mixed Models
LUQ	Language Use Questionnaire
MPO	Months Post-Onset

MRI	Magnetic Resonance Imaging
NAVS	Northwestern Assessment of Verbs and Sentences
NNB	Northwestern Naming Battery
OANB	Object and Action Naming Battery
PPT	Pyramids and Palm Trees Test
RHM	Revised Hierarchical Model
SBTT	Switching Back Through Translation
SD	Standard Deviation
SE	Standard Error
SFA	Semantic Feature Analysis
SLP	Speech-Language Pathologists
SVO	Subject-Verb-Object
T	Target language = trained language
TX	Treatment
U	Target language = untrained language
VNT	Verb Naming Test
WAB	Western Aphasia Battery

1. PROJECT OVERVIEW

Bi/multilinguals refer to individuals who use two or more than two languages frequently in their everyday lives (Grosjean, 1992). According to the U.S. census bureau, more than a third of the population in the United States speaks another language in addition to English, with Chinese being the third most spoken language following Spanish (Zeigler & Camarota, 2019).

Anomia, or trouble retrieving words and/or naming objects and actions, is a hallmark symptom of aphasia. Lexical retrieval difficulty can be differentially impacted based on a specific grammatical category, i.e., nouns or verbs (Berndt et al., 1997; Kim & Thompson, 2000; Miceli et al., 1984; Zingeser & Berndt, 1990). However, most evidence of lexical impairment in aphasia has been focused on nouns, and whether similar patterns emerge for other lexical categories (i.e., verbs) remains unknown. Studying verb retrieval in aphasia is especially important because verbs play an essential role in sentence production critical to conveying one's message (Vigliocco et al., 2011).

Bilinguals with aphasia (BWA) often show a loss of function in one or both languages. Investigating lexical-retrieval difficulty in BWA would help better understand language recovery in both first (L1) and second (L2) languages. Several studies have attempted to examine noun and verb retrieval in BWA. In general, these studies have pointed to a verb-noun dissociation with higher naming accuracy for nouns as compared to verbs (Kambanaros, 2010a; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007). This pattern of verb-noun dissociation is overall similar in both L1 and L2, suggesting that the organization of grammatical categories is shared between languages.

Discourse production is another clinical measure to calibrate language impairment in individuals with aphasia. Given that discourse tasks elicit high cognitive-linguistic demands, examining patterns of lexical impairment in spoken discourse would help identify linguistic indicators of language recovery. Nevertheless, whether similar patterns of lexical impairment emerge in different linguistic contexts remains unclear. Among previous studies examining lexical retrieval in spoken discourse in bi/multilinguals with aphasia, some have found a verb-noun dissociation in both single-word naming and discourse production (Faroqi-Shah & Waked, 2010), whereas others only observed a verb-noun dissociation in naming (Kambanaros, 2010; Dai et al., 2012).

Aphasia rehabilitation is crucial to restore language functions and thereby promote better communication for BWA. One conceptual challenge in bilingual aphasia rehabilitation is whether treatment implemented in one language results in improvement in the untreated language, i.e., cross-language generalization (Kohnert, 2009). Findings of cross-language generalization are mixed across studies, which can be attributed to a combination of factors including bilingual language history, types of treatment, and linguistic distance (Kohnert, 2009; Kuzmina et al., 2019). Cross-language generalization has been frequently reported in studies implementing treatment approaches based on lexical-semantic models (Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Roberts, 2010). Theoretically, since bilinguals have a shared semantic system, training semantic features of an item should spread activation to items sharing similar features, i.e., within-language generalization, and also to items in the untreated language, i.e., cross-language generalization (Costa et al., 2006; Hermans et al., 1998).

The majority of studies examining the effect of naming treatment in BWA have focused on nouns (Faroqi-Shah et al., 2010; Gil & Goral, 2004; Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Roberts, 2010; Kohnert & Peterson, 2012). Fewer treatment studies to date have targeted verb retrieval in bi/multilinguals with aphasia (Knoph et al., 2015, 2017; Lerman, 2020; Lerman et al., 2019; Li et al., 2020). Although positive treatment gains have been found in these verb treatment studies, the extent to which treatment and generalization effects differ from noun treatment is unclear. Hence, it is important to directly compare treatment-induced language recovery patterns between training nouns and verbs in BWA to understand whether treatment efficacy and efficiency are modulated by a specific grammatical category.

Generalization beyond the word level is another indicator of the effectiveness of aphasia treatment. However, this type of generalization has not been systematically investigated in previous research. Several studies targeting verb retrieval have reported generalizations to sentence and discourse production (Goral et al., 2012; Knoph et al., 2017; Lerman, 2020; Lerman et al., 2019; Li et al., 2020). Evidence from previous research has suggested spreading activation from verbs to their thematic roles (Ferretti et al., 2001; McRae et al., 2005). Hence, training the target verb should promote activation of its agent and/or patient, leading to increased production of complete utterances.

The bulk of evidence in bilingual language recovery and rehabilitation has been limited to individuals speaking Indo-European languages, such as Greek-English and Spanish-English (Bogka et al., 2003; Kambanaros, 2010a; Kiran et al., 2013). Findings from these studies provide evidence of bilingual language rehabilitation in typologically similar languages. However, whether similar patterns emerge in typologically dissimilar languages is unknown (e.g., Mandarin-English). The current project would grow the evidence base for bilingual aphasia rehabilitation by examining patterns of impairment and treatment-induced language recovery between nouns and verbs in Mandarin-English BWA.

As highlighted above, previous studies in BWA have found a verb-noun dissociation in single-word naming, i.e., lower naming accuracy for verbs than nouns. Yet, whether a similar pattern of lexical impairment emerges in discourse production is unclear, particularly in individuals speaking typologically dissimilar languages, i.e., Chinese-English BWA. In bilingual aphasia rehabilitation, while positive treatment gains have been reported when training either nouns or verbs, the extent to which training nouns and verbs show similar patterns of treatment and generalization effects remains unknown. In the current work, these issues were investigated through two specific goals: (1) to examine patterns of verb and noun impairment in single-word naming and discourse production in Mandarin-English BWA (Study 1), and (2) to compare patterns of treatment-induced language recovery between training nouns and verbs in the same group of Mandarin-English BWA (Study 2).

The following section (Chapter 2) describes theories and empirical findings in the literature that are relevant to language recovery and rehabilitation of verbs and nouns in BWA. It covers several topics, including verb and noun processing in healthy bilinguals, verb and noun impairment in BWA, and bilingual aphasia rehabilitation targeting these grammatical categories. Overall, this chapter provides fundamental information regarding patterns of verb and noun recovery and serves to support the interpretation of findings from

Studies 1 and 2.

Chapter 3 sets the stage for the studies detailed in Chapters 4 and 5 by recapping the gaps in the current literature and what remains to be investigated regarding the patterns of lexical impairment and treatment-induced language recovery for nouns and verbs in Mandarin-English BWA.

The next two chapters present findings from two separate studies. The first study (Chapter 4) examined patterns of verb and noun impairment in single-word naming and discourse production in twelve Mandarin-English BWA. Lexical retrieval of nouns and verbs was measured via standardized assessments of picture naming and discourse production in both Mandarin and English. Mixed-effects regression models were conducted to estimate performance on these tasks as a function of grammatical category.

The second study (Chapter 5) investigated patterns of treatment-induced language recovery between training nouns and verbs in the same twelve participants via a cross-over treatment design. Eight of these participants completed a two-cycle treatment, one for nouns and one for verbs, and the other four participants completed a one-cycle treatment targeting either nouns or verbs. Direct treatment gains, within-language, and cross-language generalizations were captured via weekly naming probes in both treated and untreated languages. A series of mixed-effects models were fit to the item-level naming accuracy data to assess the effect of treatment gains and generalizations at the group level. Individual effect sizes were further calculated to capture individual variability. Additionally, group-level generalizations to sentence and discourse production, as well as to untrained naming tasks were measured via standardized language assessments and analyzed as a function of the target grammatical category.

2. LITERATURE REVIEW

This chapter is divided into three main sections. The first section describes the current theoretical models of lexical processing and supporting empirical evidence for noun and verb retrieval in healthy bilinguals. The second section provides a review of the literature on lexical impairment focusing on nouns and verbs in BWA, and the third section describes the state of the literature on bilingual aphasia rehabilitation targeting lexical retrieval of nouns and verbs. These sections inform hypotheses and support the interpretation of findings in Studies 1 and 2.

2.1 Lexical processing in healthy bilinguals

Bilingual lexical processing (comprehension and production) has been widely investigated through a variety of approaches, and this project focuses specifically on bilingual lexical production. The following section first reviews contemporary models of bilingual language processing relevant to lexical production and then discusses current evidence documenting the nature of noun and verb retrieval in bilinguals.

2.1.1 Theoretical models of bilingual lexical processing

Among many models of bilingual lexical processing that have been proposed (de Groot, 1992; Kambanaros & van Steenbrugge, 2006; Kroll & Stewart, 1994; Kroll & Tokowicz, 2005; Poulisse & Bongaerts, 1994), the *Revised Hierarchical Model*, *Distributed Feature Model*, and *Inhibitory Control Model* are discussed below.

Revised Hierarchical Model

One early influential model, the *Revised Hierarchical Model* (RHM; Kroll & Stewart, 1994; Kroll et al., 2010), posited separated lexical representations with a shared semantic system in bilinguals. The RHM further built a relatively strong theoretical foundation for predicting lexical production in both languages (Kroll & Stewart, 1994). During the early stages of language proficiency when L2 is less proficient than L1, the RHM makes two primary assumptions: (1) connections are stronger between the conceptual system and L1 than between the conceptual system and L2, and (2) lexical connections are stronger from L2 to L1 than from L1 to L2 (Kroll & Stewart, 1994). The RHM model has been recently updated to account for levels of representation in bilingual lexical production (Kroll & Tokowicz, 2005). In this updated model, three levels of representation are involved: a shared semantic level in which a stimulus (e.g., pictured object) initiates word production, a lemma level that includes distinct lexical representations in each of the languages, and a phonological system in which specific phonemes in each language are activated from a common phonological pool and are adapted for the target language. Further, a language cue (i.e., a word related to the meaning or form of the target) is encoded as part of the semantic level to signal information about which language needs to be spoken and hence may serve to reduce between-language lexical competition (Miller & Kroll, 2002).

At the lexical selection/lemma level of bilingual lexical production, syntactic properties such as syntactic category (e.g., verb vs. noun), tense, gender, and number are often included and become available upon selection and activation (Kambanaros, 2010b; Levelt et al., 1999). One key question during bilingual lexical selection is whether lexical representations of the non-target language are activated. One early view argued that the activation of lexical representations in one language does not interact with lexical representations in the other language (Kroll et al., 2010; Kroll & Stewart, 1994). The RHM, which makes a distinction between L1 and L2 lexicons, was the first model addressing the issue of shared vs. separate representations in bilingual language processing (Kroll & Stewart, 1994). However, there has been evidence suggesting that lexical access is non-selective since lexical representations from both L1 and L2 may compete with each other (Costa et al., 2006; Dijkstra & van Heuven, 2002; Marian et al., 2003; Marian & Spivey, 2003; Pashler & Tokowicz, 2013). These findings suggest a parallel activation in bilingual lexical production (Costa et al., 1999; de Bot, 1992; Hermans et al., 1998; Poulisse & Bongaerts, 1994).

Distributed Feature Model

At the semantic representation level of bilingual lexical processing, a generally accepted notion is that semantic processes are shared between languages (Costa et al., 1999; de Groot, 1992; Francis, 2005; Hermans et al., 1998; Kambanaros & van Steenbrugge, 2006; Kroll & Stewart, 1994; Kroll & Tokowicz, 2005). Many previous studies have supported a shared semantic system via both behavioral tasks (Chen & Ng, 1989; Tzelgov & Eben-Ezra, 1992) and neuroimaging techniques (Illes et al., 1999). For instance, some studies have found that lexical decisions are faster when a word is preceded by a semantically-related word than by a semantically-unrelated word even when the prime appears in the non-target language (Chen & Ng, 1989; de Groot & Nas, 1991), suggesting that semantic representations are shared across languages. However, there are other circumstances under which semantic processes are separate or partially shared. The *Distributed Feature Model* (de Groot, 1992; Van Hell & de Groot, 1998) has posited that the degree to which the semantic processes are shared across languages depends on the lexical category, i.e., concrete vs. abstract or cognates vs. non-cognates. Cognates are translation equivalents that share phonological or orthographical forms across languages (e.g., *rose* in English and *rosa* in Spanish). This model further predicts that the degree of overlap across translation equivalents determines the time it takes for a bilingual speaker to translate from one language to the other. Previous studies using translation and word association tasks have shown that responses to translation equivalents were faster if the word pairs were concrete nouns or cognates, and that word associations were similar across languages for concrete words or cognates as compared to abstract words or noncognates (Van Hell & de Groot, 1998). These findings indicate that the extent to which semantic representations are shared across languages is influenced by the lexical category.

The *Distributed Feature Model* has further posited that frequent use of a word in bilinguals results in strong connections between the semantic-conceptual system and each of the bilingual lexicon. Different from the RHM mentioned above (Kroll & Stewart, 1994), this model further accounts for balanced bilinguals, i.e., individuals who are proficient in both L1 and L2, and suggests that connections are equally strong between the semantic-conceptual system and both lexicons, as well as between L1 and L2 lexicons.

Inhibitory Control Model

If lexical representations in both languages are activated in parallel (Costa et al., 2006; Pashler & Tokowicz, 2013), then a crucial question is: how do bilinguals manage to select the target language for production? Many different views have been proposed to address the underlying mechanisms of bilingual language selection (Costa et al., 1999;

Green, 1998; Hermans et al., 1998). One account that has drawn wide attention is the *Inhibitory Control Model* (ICM; Green, 1998), which has assumed that language selection is achieved by inhibiting lexical representations in the non-target language. Previous studies using code-switching paradigms have reported an asymmetrical switch cost with longer response times when switching from L2 to L1 as compared to from L1 to L2 in unbalanced bilinguals, and a relatively symmetrical switch cost in balanced bilinguals (Costa et al., 2006). These findings suggest that highly proficient bilinguals may acquire an early language selection mechanism that allows them to select the target language without the inhibition processes (Meuter & Allport, 1999).

Summary

Several theoretical models have been put forth to explain bilingual lexical production. In general, these models propose at least three levels of lexical processing: a shared semantic representation level, lemma/lexical selection level, and separated lexical representation levels. Recent studies have suggested parallel activation of both L1 and L2 lexicons during bilingual lexical processing. In addition, bilingual inhibitory control mechanism is involved to facilitate lexical selection in the target language. Nevertheless, the bulk of evidence has been derived from nouns (Kroll & Stewart, 1994; de Groot, 1992), and whether the same notion of a shared semantic system can be applied to verbs is unknown. Verbs are important as they pose linguistic differences crucial for sentence construction (Vigliocco et al., 2011). According to previous research, syntactic information for verbs is represented at the lemma level with each piece of syntactic information (e.g., syntactic category, tense) being represented by a separate node, and then, being activated whenever a verb is used (Levelt et al., 1999; Pickering & Branigan, 1998; Roelofs, 1992). There has been research showing that bilinguals tend to use L1 syntactic structure and thematic roles during L2 sentence production, and also generate L1 prime structures before completing an L2 target structure (Salamoura & Williams, 2007). Hence, although previous models of bilingual lexical processing have been tested on nouns, current evidence points to a shared semantic representation level in bilingual verb processing.

2.1.2 Verb and noun processing in healthy bilinguals

As mentioned in the previous section, the differences in processing verbs and nouns have not been widely investigated in bilinguals. Among the studies that have examined this issue, three main findings have shown: (1) fewer word associations for verbs than nouns (Van Hell & de Groot, 1998; Gentner, 1981), (2) more word translations for verbs than nouns (Prior et al., 2007), and (3) slower and less accurate responses to actions than objects in picture naming (Jia et al., 2006; Kambanaros, 2016; Li et al., 2019; Faroqi-Shah et al., 2021). These studies indicate a verb-noun dissociation and imply that bilingual lexical organization may differ between grammatical categories. Several psycholinguistic and neurolinguistic accounts have been proposed to explain this verb-noun dissociation; however, they were primarily derived from the monolingual literature.

2.1.2.1 Psycholinguistic accounts for verb-noun differences

Verbs and nouns differ at the semantic level. For example, verbs denote abstract events and actions that are temporally transient (i.e., lower imageability than nouns), whereas nouns refer to concrete entities (i.e., higher imageability than verbs; Gentner, 2006). Research has argued that the verb-noun dissociation may result from weakened links between semantic and lexical representations, degraded lexical representations, or rapid decay of the activated lexical node for verbs (Dell et al., 1997). One lexical-semantic variable that significantly impacts verb and noun retrieval is *imageability* (Bird et al., 2003; Bird, Howard, et al., 2001), which is generally lower for verbs than nouns. This view has been corroborated in psycholinguistic studies as some did not find a verb-noun dissociation when word imageability was controlled for (Berndt et al., 2002; Shapiro & Caramazza, 2003). In bilinguals, previous studies have suggested a lower cross-linguistic overlap in verb meanings compared to noun meanings as verbs tend to be more ambiguous (Gentner, 1981; Prior et al., 2007; Van Hell & de Groot, 1998). These findings also support the *Distributed Feature Model*, which posits that the extent to which semantic representations are shared between L1 and L2 in bilinguals varies by the word category (de Groot, 1992), as highlighted before.

Verbs in many languages carry rich syntactic and morphological information in sentence production critical to conveying one's message (Vigliocco et al., 2011). For example, verbs in English may require argument structures. A thematic role is assigned to each argument in the form of a noun phrase for the sentence's main verb (Ferretti et al., 2001). Verbs in many languages are also morphologically more complex than nouns as verbs carry rich lexical inflections (Vigliocco et al., 2011). Therefore, the verb-noun dissociation identified in previous studies could stem from the processing of arguments or morphological forms of a verb (Gentner, 2006). The verb-noun dissociation has also been observed in "verb-friendly" languages, i.e., Mandarin Chinese (Li et al., 2019), in which verbs carry little if any syntactic or morphological information (Gentner, 1981). These findings suggest that the differences in syntactic or morphological complexity of verbs may not by themselves account for the verb-noun dissociation.

Another variable that may influence the verb-noun dissociation is name agreement (Kauschke & Von Frankenberg, 2008; Szekely et al., 2005), i.e., the variety of names produced for a given word. Previous studies examining object and action naming across several different languages have shown that lower name agreement significantly predicted longer reaction times for action versus object naming (Bates et al., 2003; Szekely et al., 2005; Faroqi-Shah et al., 2021), suggesting that name agreement may play a significant role in verb and noun processing. Alternatively, longer response times for words with lower name agreement could also reflect the different lexical representations competing for selection due to increased time to resolve conflict (Szekely et al., 2005).

2.1.2.2 Neural models for verb-noun differences

Two main neuroanatomical models have been put forth to explain the verb-noun dissociation (Cappa & Perani, 2003; Faroqi-Shah et al., 2018; Miozzo et al., 2010; Petersen et al., 1988; Shapiro et al., 2006; Tranel et al., 2005; Vigliocco et al., 2011; Wise et al., 1991). One perspective posits that nouns and verbs are represented in distinct cortical regions, with verb retrieval involving left frontal regions and noun retrieval engaging left temporal regions (Petersen et al., 1988; Shapiro et al., 2006). Another viewpoint suggests that the morphosyntactic processes associated with noun and verb processing, rather than nouns and verbs *per se*, are represented in separate networks (Shapiro et al., 2006). This second account posits that verbs are linked with left frontal regions as they carry rich morphological and syntactic information as compared to nouns (Damasio & Tranel, 1993).

Previous neuroimaging studies have associated brain activation in left frontal regions with longer reaction times for verbs, suggesting that verb processing requires a higher degree of cognitive demand than noun processing (Berlingeri et al., 2008; Faroqi-Shah et al., 2018). In addition to the left frontal cortex, other neuroimaging studies have revealed brain activations in the left middle temporal (Damasio et al., 2001; Faroqi-Shah et al., 2018; Martin et al., 1995; Shapiro et al., 2006; Yokoyama et al., 2006) or parietal regions (Berlingeri et al., 2008) during verb processing. Previous neuroimaging evidence in healthy bilinguals has also pointed out a diverse pattern of noun and verb representation in both languages. For example, a Chinese-English fMRI study reported overlapping and distributed neural regions in frontal, parietal, and occipital regions when processing nouns and verbs in Chinese, whereas nouns and verbs evoked a more focused activation in the left frontal and parietal regions in English (Li, 2009). Altogether, findings from these studies suggest that the noun-verb dissociation is not simply due a dichotomy in brain regions.

Summary

Many studies investigating noun and verb retrieval in healthy bilinguals have pointed to a verb-noun dissociation, that is, worse performance in verbs compared to nouns across psycholinguistic tasks. Different theoretical accounts have been put forth to explain the verb-noun dissociation. Although many of these models were derived from the monolingual literature, they provide potential explanations for verb and noun processing in healthy bilinguals. Altogether, these models inform us that the differences between verbs and nouns cannot be solely explained by a single factor, rather it is an artifact of the many processing dimensions that separate these two grammatical categories (Szekely et al., 2005).

2.2 Lexical processing in bilingual aphasia

The growing bilingual population coincides with an overall increase of older people at risk for stroke and dementia (Hoeffel et al., 2012). In bilinguals, aphasia may occur in one or both languages and demonstrate diverse patterns of language recovery given complex cross-language interactions (Fabbro, 2001; Lorenzen & Murray, 2008; Paradis, 2001). Anomia, or trouble retrieving words and/or naming objects and actions, is a common symptom in individuals with aphasia. Studying bilinguals with aphasia (BWA) enables a direct comparison between L1 and L2 as each patient serves as his/her control (Nadeau, 2019). The next section will review differential patterns of lexical impairment in BWA, followed by a discussion of lexical impairment focusing on verbs and nouns.

2.2.1 Language impairment in bilingual aphasia

Early approaches in bilingual aphasia studies have categorized language impairment into several different patterns: (1) *parallel impairment* in which L1 and L2 are equally impaired following brain damage, (2) *differential impairment* in which one language shows more impairment than the other relative to premorbid proficiency levels (i.e., less proficient language is more impaired than more proficient language), and (3) *selective impairment* in which one language is selectively impaired with no obvious deficits in the other language (Fabbro, 2001; Paradis, 2001).

Past studies suggest that differential patterns of language recovery most likely result from a combination of individual and language factors, such as the L2 age of acquisition

(AoA), premorbid language proficiency, frequency of language use, linguistic distance, and damage in the language-control network (Goral et al., 2012; Kuzmina et al., 2019; Paradis, 2001). Studies in bilinguals with earlier L2 AoA have shown comparable levels of impairment in both languages after brain damage (Kiran & Roberts, 2010), whereas bilinguals with later L2 AoA typically demonstrate better post-stroke performance in L1 than in L2 (Kuzmina et al., 2019). Premorbid language proficiency can also significantly influence language impairment in BWA. Higher language proficiency has been associated with better naming performance in BWA (Muñoz & Marquardt, 2003; Peñaloza et al., 2020), suggesting that a pre-morbidly more proficient language is better preserved after brain damage (Kuzmina et al., 2019). A higher degree of lifetime exposure and higher frequency of daily usage have also been associated with more optimal language performance in BWA (Kastenbaum et al., 2019; Peñaloza et al., 2020). For example, one study showed that pre-stroke L2 proficiency, which was determined by AoA, daily usage, educational history, lifetime exposure, lifetime confidence, family proficiency, and language ability rating, significantly predicted post-stroke lexical-semantic performance in 27 Spanish-English BWA (Peñaloza et al., 2020), suggesting that premorbid proficiency and frequency of usage play crucial roles in bilingual language recovery (Peñaloza & Kiran, 2019). Additionally, linguistic distance has been linked with bilingual aphasia recovery when testing differential impairment in L1 and L2 (Lorenzen & Murray, 2008; Kendall et al., 2015). Previous studies have found that languages with phonological and orthographic similarities (i.e., shorter cross-language distance) result in faster and more accurate lexical processing (Kendall et al., 2015). Furthermore, differences in language impairment can be driven by damage to the language-control network. According to the neurocognitive model, the language-control network is comprised of cortical and subcortical circuits and is responsible for the selection, inhibition, and switching of a given language (Abutalebi & Green, 2007). Evidence from neuroimaging and neuropsychological studies suggests that lesion damage to any regions in this network may affect the extent to which BWA recover complete use of their languages (Abutalebi & Green, 2007; Green & Abutalebi, 2008). Altogether, these findings indicate that language impairment in BWA is not a product of one single determiner, but rather stems from complex interactions among factors including AoA, lifetime exposure, frequency of usage, pre-stroke language proficiency, linguistic distance, and lesion damage to the language-control mechanism.

2.2.2 Verb and noun processing in aphasia

Before we discuss verb and noun processing in bilingual aphasia, we will review monolingual aphasia where the bulk of evidence comes from.

Monolinguals

Most research on verb and noun processing in individuals with aphasia has been conducted in monolingual speakers (Berndt et al., 1997; Chen & Bates, 1998; Hillis & Caramazza, 1995; Shapiro et al., 2000). Some of these studies have revealed more impairment in lexical retrieval of verbs than nouns (Bastiaanse & Jonkers, 1998; Chen & Bates, 1998; Hillis & Caramazza, 1995; Marshall et al., 1998; Tsapkini et al., 2002), which is evidenced in a variety of languages such as English (Shapiro et al., 2000), Mandarin Chinese (Bates et al., 1991), Dutch (Bastiaanse et al., 2002), and Greek (Tsapkini et al., 2002). In comparison, other studies have found worse lexical retrieval of nouns than verbs

(Berndt et al., 1997; Caramazza & Hillis, 1991; Rapp & Caramazza, 2002; Shapiro et al., 2000). These diverse patterns of verb and noun impairment likely result from a complex interplay among the conceptual and linguistic variations between verbs and nouns, language-specific properties, as well as individual aphasia characteristics (Kambanaros, 2010b). For example, some studies have argued that verb impairment is associated with agrammatism in Broca's or other non-fluent types of aphasia due to lesions in the left frontal regions (Caramazza & Hillis, 1991; Damasio & Tranel, 1993). Other studies suggest that noun impairment is typically associated with anomic aphasia at the level of the word form (Berndt et al., 1997; Miceli et al., 1984; Zingeser & Berndt, 1990; Kay & Ellis, 1987).

Bilinguals

Lexical impairment in BWA can also differ by a specific grammatical class. Yet, less research has attempted to compare noun and verb retrieval in BWA. As summarized in Table 2.1, six studies have investigated both verb and noun retrieval in bi/multilinguals with aphasia (Kremin & De Agostini, 1995; Sasanuma & Park, 1995; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Faroqi-Shah & Waked, 2010; Kambanaros, 2010a).

Two early single-case studies (Kremin & De Agostini, 1995; Sasanuma & Park, 1995) reported no differences between verbs and nouns in any of the languages being assessed. The first study tested picture naming in L2 of a trilingual patient, who showed comparable performance of naming accuracy between verbs and nouns, but no results were reported for L1 or L3 (Kremin & De Agostini, 1995). The second study examined lexical retrieval in auditory comprehension, reading, oral production, and writing modalities in both L1 and L2 of a Korean-Japanese BWA (Sasanuma & Park, 1995). Results revealed greater lexical retrieval difficulties in L2 (Japanese) than in L1 (Korean), but there was no difference between verbs and nouns in any assessment modalities.

Two recent studies found differences between verbs and nouns in picture naming (Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007). Poncelet et al. (2007) compared object and action naming in three BWA (one Turkish-English, two German-French) using An Object and Action Naming Battery (OANB; Druks & Masterson, 2000). Results showed a higher naming accuracy for nouns than verbs in both L1 and L2 for all participants. The other study investigated verb and noun comprehension and production in 12 late Greek-English BWA and 12 matched healthy controls (Kambanaros & van Steenbrugge, 2006). While no between-group differences were found in verb or noun comprehension, performance in picture naming was significantly worse in BWA as compared to healthy controls. The patient group further showed worse naming performance in verbs than nouns in both L1 and L2.

Verb and noun retrieval have also been investigated in connected speech (Kambanaros, 2010a; Faroqi-Shah & Waked, 2010; Dai et al., 2012). One study has examined verb and noun retrieval in narrative speech (in addition to single-word comprehension and picture naming) in a high-proficiency Arabic-French-English trilingual with aphasia (Faroqi-Shah & Waked, 2010). Another study investigated verb and noun retrieval in connected speech (in addition to picture naming) in 12 late Greek-English BWA (Kambanaros, 2010a). Both studies found remarkable impairment for verbs as compared to nouns in picture naming. In discourse production, the trilingual patient produced fewer verbs than nouns, whereas late Greek-English BWA produced fewer nouns than verbs. Further, the Kambanaros study revealed no significant correlation between action naming and lexical retrieval of verbs in connected speech in either L1 or L2. These findings suggest that some BWA can produce a within-normal number of verbs in connected speech despite verb impairment in picture naming. The authors argued that verb retrieval in BWA might be facilitated by sentence frames available in connected speech, and by semantic and pragmatic factors in both languages (Kambanaros, 2010a). In comparison, noun retrieval in connected speech might be hindered by lexical-external variables related to macrostructural features such as the thematic coherence (Glosser & Deser, 1991).

In sum, these previous studies emphasize two important notions about verb and noun impairment in BWA. First, evidence from single-word naming has suggested a verb-noun dissociation with lower naming accuracy for verbs than nouns (Faroqi-Shah & Waked, 2010; Kambanaros, 2010a; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007). However, the evidence in other linguistic contexts (i.e., discourse production) is mixed across studies (Faroqi-Shah & Wakes, 2010; Kambanaros, 2010a). The presence of a verb-noun dissociation in picture naming but not in connected speech resonates with findings from previous monolingual studies (Bastiaanse & Jonkers, 1998; Berndt et al., 1997; Luzzatti et al., 2002; Zingeser & Berndt, 1990). Second, the verb-noun dissociation has been observed in both L1 and L2 of BWA (Kambanaros, 2010a; Miozzo et al., 2010). This dissociation between grammatical categories is less likely driven by the L2 AoA or language proficiency, as some participants acquired their L2 at an earlier age (Hernàndez et al., 2008; Sasanuma & Park, 1995) and others acquired it at a later age (Faroqi-Shah &

Waked, 2010; Kambanaros, 2007, 2009; Kambanaros & van Steenbrugge, 2006). Results from these previous studies suggest that the verb-noun dissociation in BWA is not specific to one language and may instead arise from the conceptual or linguistic differences between nouns and verbs (Kambanaros, 2010b). Different theoretical accounts have been put forth to explain the verb-noun impairment in aphasia, which will be reviewed in the next two sections.

Table 2.1. Summary of studies comparing verb and noun retrieval in bi/multilinguals with aphasia.

Study	**Patients**	**Languages**	**Age of Acquisition**	**Proficiency**	**Tasks**	**Main findings**
Kremin & De Agostini (1995)	1	Bergamac (L1) – Italian (L2) – German (L3)	Early	High	Picture naming in L2	V = N
Sasanuma & Park (1995)	1	Korean (L1) – Japanese (L2)	Early	High	Picture naming and spontaneous speech	L2 < L1 for both V and N
Kambanaros & van Steenbrugge (2006)	12	Greek (L1) – English (L2)	Late	High	Picture naming	N > V in L1 and L2
Poncelet et al., 2007	3	P1: Turkish (L1) – English (L2) P2 & P3: German (L1) – French (L2)	N/A	N/A	Picture naming	N > V in L1 and L2
Faroqi-Shah & Waked (2010)	1	Arabic (L1) – French (L2) – English (L3)	Late	High	Single word comprehension, picture naming, narrative production	N > V in *picture naming* and *narrative speech* in all three languages
Kambanaros (2010a)	12	Greek (L1) – English (L2)	Late	High	Picture naming, spontaneous speech	N > V in *picture naming* and N < V in *connected speech* in L1 and L2

Note: V: verb, N: noun; L1: first language, L2: second language; P1: patient #1, P2: patient #2, P3: patient #3; N < V: worse performance in nouns than verbs; N > V better performance in nouns than verbs; V = N: no significant difference between nouns and verbs; N/A: information not available in the study.

2.2.2.1 Psycholinguistic accounts for verb-noun impairment

Previous models of lexical processing have been proposed and set as foundation to explain the lexical breakdown in individuals with aphasia. The Connectionist Model of lexical access assumed three layers of nodes connected by excitatory connections: semantic features, lexical nodes, and phonological segments (Dell et al., 1997, 2004; Foygel & Dell, 2000). During lexical selection, semantic representations spread activation to different lexical nodes which compete for selection. During phonological encoding, activation to the selected lexical node continues to spread to different phoneme nodes, which are selected if their activation exceeds that of other competing nodes (Dell et al., 1997). According to the Lemma Model of lexical access (Levelt et al., 1999), following a first stage of conceptual processing, word generation proceeds through lexical selection, morphological and phonological encoding, phonetic encoding, and articulation, each produces its own characteristic output representation. In addition, the speaker exerts some degree of output control via self-monitoring of both internal and overt speech, i.e., errors, dysfluencies. Overall, these models predict that speech errors may fall into three levels of breakdown: (1) semantic-conceptual, (2) lexical-grammatical (i.e., lemma), and (3) lexical-phonological (Bates et al., 1991; Druks, 2002).

At the semantic-conceptual level, a semantic error occurs because semantically-related words share features (Dell et al., 1997; Foygel & Dell, 2000). A non-target item can therefore be mistakenly selected because its activation surpasses that of the target word. As highlighted in the previous section, verbs in general have greater semantic complexity relative to nouns because verbs are more ambiguous and have weaker cross-linguistic connections in bilingual lexicons (Gentner, 1981; Prior et al., 2007; Van Hell & De Groot, 1998). This view has been supported by previous studies showing a significant effect of imageability for both object and action naming in BWA, that is, a higher naming accuracy of concrete nouns relative to abstract verbs (Poncelet et al., 2007). Picture imageability for action names is generally lower than for object names, as action names require an agent initiating the action to be depicted in picture stimuli, whereas objects can be depicted independently (Bird et al., 2001; Kohn et al., 1989). Hence, action names may be more vulnerable to damage at the semantic-conceptual level than nouns. Nevertheless, some studies examining action and object comprehension in BWA have not reported a verb-noun dissociation in either L1 or L2 (Faroqi-Shah & Waked, 2010; Kambanaros, 2010a; Kambanaros & van Steenbrugge, 2006), suggesting that verb deficits cannot be solely attributed to a central deficit at the semantic-conceptual level of lexical retrieval (Kambanaros, 2010b).

Damage at the lemma level may also contribute to the verb-noun dissociation in bilingual aphasia. The interactive models assume that semantic representations spread activation to related lexical nodes that compete for selection, then the most activated lexical node of the proper syntactic category is selected (Costa et al., 2000, 2006; Dell et al., 1997). Hence, verb deficits may arise from insufficient activation of the target verb at the lexical selection stage. Grammatical and syntactic information of verbs and nouns is stored at the lemma level and becomes available upon its selection and activation (Ferreira, 1996; Garrett, 1975; Levelt et al., 1999; Vigliocco & Franck, 1999). Nouns usually carry grammatical properties such as gender and number, whereas verbs typically carry information about tense, person, and mood. Some people argue that the verb-noun dissociation might involve a breakdown in morphological inflections of verbs (Shapiro et al., 2000; Tsapkini et al., 2002), suggesting that verb deficits arise at the lemma level where grammatical class information is stored (Caramazza & Hillis, 1991; Rapp & Caramazza, 2002; Tsapkini et al., 2002). Verbs in many languages also require argument structures (i.e., subject, object), whereas nouns do not (Gentner, 2006; Vigliocco et al., 2011). These distinct syntactic and grammatical properties make verbs more complex than nouns and may lead to a verb-noun dissociation. This view has been previously corroborated in studies examining verb and noun processing in BWA (Faroqi-Shah & Waked, 2010; Kambanaros & van Steenbrugge, 2006). Specifically, BWA produced a high proportion of semantic substitutions when naming pictures of action verbs, and the naming accuracy of verbs improved significantly following phonemic cues. These findings suggest that the verb deficit may occur when information flows from concept to lemma because the lexical node of the target verb might have failed to achieve the level of activation needed to exceed other competing nodes.

Finally, the verb-noun dissociation in BWA may also stem from the phonological level. According to the interactive activation models, speech errors occur because the target phonemes may interfere with other activated competitors and are mistakenly replaced by those non-target phonemes (Dell et al., 1997). However, this account may not be sufficient to account for the verb-noun dissociation in BWA, as very few phonological errors were identified during verb retrieval tasks (Kambanaros & van Steenbrugge, 2006).

2.2.2.2 Neural models for verb-noun impairment

Deficits in verb and noun retrieval can also be attributed to neural differences between these grammatical categories. There are two accounts of verb and noun representation based on prior neuroimaging studies. One view argues for a complete frontal-temporal dichotomy, from which verb deficit is associated with left frontal lesions (Caramazza & Hillis, 1991; Damasio & Tranel, 1993; Miceli et al., 1984; Piras & Marangolo, 2007, 2010; Zingeser & Berndt, 1990), and noun deficit is correlated with left temporal lesions (Damasio & Tranel, 1993). Evidence has suggested that activation in left frontal regions relates to more cognitive demand for verbs as compared to nouns (Bedny & Thompson-Schill, 2006; Berlingeri et al., 2008; Faroqi-Shah et al., 2018). However, recent studies do not support the frontal-temporal dichotomy, as verb retrieval deficit has also been associated with lesions in medial-superior temporal, posterior-occipitotemporal, inferior parietal, and insular/subcortical regions (Aggujaro et al., 2006; Mätzig et al., 2009; Tranel et al., 2008). Another account posits no distinct neural architecture between nouns and verbs. But instead, these grammatical categories are represented in overlapping neural regions (Vigliocco et al., 2011). This view has been borne out by previous neuroimaging studies, in which no significant differences in brain activation were found between verbs and nouns (Crepaldi et al., 2011, 2013). A meta-analysis of the neural representation of verbs and nouns showed that verbs activate frontal and temporal regions, with a more extensive temporal activation (Faroqi-Shah et al., 2018). Although evidence is mostly observed in monolinguals, these findings support neither the frontal-temporal dichotomy account nor the complete overlap account, suggesting that neural representation of verbs and nouns involves both specific and non-specific regions to each grammatical category. Note that the relative ambiguity about these neuroanatomical accounts was not aimed to be addressed in the current project.

Summary

Different accounts have been proposed to explain the verb-noun dissociation in BWA. From a psycholinguistic perspective, findings from previous bilingual aphasia studies favor a notion that the verb-noun dissociation may arise from the semantic representation level or the lemma level where morphosyntactic information is stored. On the other hand, the neuroanatomical views of verb and noun representation suggest that verb deficits are associated with brain damage in distinct cortical regions (i.e., left frontal regions). Overall, the dissociation between nouns and verbs is likely stemmed from complex interactions among a variety of factors, including the conceptual and linguistic properties of verbs and nouns, cross-language differences, as well as individual heterogeneity (Kambanaros, 2010b). In BWA, the verb-noun dissociation has been consistently observed across languages regardless of the pre-morbid language proficiency, indicating that bilingual lexicons are primarily affected by different grammatical categories rather than the specific language in which the word is produced (Kambanaros, 2010b). However, these views warrant future investigations in broader bilingual populations.

2.3 Bilingual Aphasia Treatment

Findings from previous studies in bilingual lexical processing provide a theoretical foundation for the rehabilitation of noun and verb retrieval in BWA. Yet, the bulk of evidence in bilingual aphasia rehabilitation has been limited to noun treatment (Ansaldo et al., 2008; Gil & Goral, 2004; Goral et al., 2010, 2012; Edmonds & Kiran, 2006). Verbs are also commonly affected in individuals with aphasia and are equally important as nouns given that verbs play a critical role in sentence formulation. Hence, it is essential to fill this gap and investigate whether similar patterns of treatment-induced language recovery emerge between verbs and nouns in BWA. Bilingual aphasia rehabilitation also comes with a host of clinical challenges, including limited access to effective bilingual treatment and a shortage of bilingual speech-language pathologists (SLPs). Several conceptual challenges also exist in bilingual aphasia treatment (Peñaloza & Kiran, 2019), such as which language to target, what type of treatment elicits the most optimal recovery outcomes, and whether treatment gains can be generalized to untrained items (i.e., within-language generalization) and to the untreated language (i.e., cross-language generalization). In addition, most evidence of bilingual aphasia rehabilitation has been derived from individuals speaking Indo-European languages (Edmonds & Kiran, 2006; Kiran & Roberts, 2010). The rise in the number of Chinese-speaking individuals in the U.S. also coincides with an overall increase in older people at risk for developing stroke and dementia (Hoeffel et al., 2012). However, the access to receiving bilingual speech therapy is limited for this population given a shortage of bilingual Chinese-speaking SLPs. The following paragraphs review treatment efficacy and generalization effects in BWA, including a description of current treatment approaches targeting lexical retrieval of nouns and verbs.

2.3.1 Treatment efficacy and generalization effects in bilingual aphasia

Previous treatment studies targeting word retrieval in BWA have revealed positive treatment gains in the trained language following treatment in either L1 or L2 (Abutalebi et al., 2009; Faroqi-Shah et al., 2010; Gil & Goral, 2004; Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Roberts, 2010; Knoph et al., 2015, 2017; Lerman, 2020; Lerman et al., 2019; Li et al., 2020; Meinzer et al., 2007; Peñaloza & Kiran, 2019). However, most of these studies are single-case or case series that differ considerably in outcome measures. Some studies examined changes in performance on standardized assessments, such as the Bilingual Aphasia Test (BAT; Paradis, 1987; Gil & Goral, 2004; Abutalebi et al., 2009), whereas others investigated changes in performance on the treatment probes (Edmonds & Kiran, 2006; Li et al., 2020). Participants in these studies also highly varied in their L2 AoA, pre-morbid language proficiency, lesion characteristics, and more. Although the individual variability is high across previous studies, findings suggest that L1 and L2 are equipotent in their potential to promote treatment gains.

In addition to the treatment acquisition effect, another measure of positive therapy outcome is the within-language generalization, i.e., generalization to semantically-related items in the trained language. According to previous models of lexical processing (Dell, 1986; Levelt et al., 1999) and the spreading activation theory (Collins & Loftus, 1975), semantic representations of a target word spread activations to multiple lexical nodes of words that share similar semantic features. Thus, training semantics of an item should strengthen the semantic network, leading to generalization to semantically-related untrained items.

A treatment is more effective if training one language can generalize to the untreated language, i.e., cross-language generalization. Nevertheless, findings of cross-language generalization are inconsistent across previous studies. While some studies have reported cross-language generalization in addition to a direct treatment gain (Edmonds & Kiran, 2006; Goral et al., 2012; Kiran & Iakupova, 2011; Kiran & Roberts, 2010; Lerman et al., 2019; Li et al., 2020; Miertsch et al., 2009), others have found a direct treatment gain (Galvez & Hinckley, 2003) or generalization to semantically-related translations (Kiran et al., 2013; Li et al., 2020). Theoretically, differential patterns of cross-language generalization can be explained in the context of bilingual inhibitory control. When there is no cross-language generalization, cross-language inhibition mechanisms may have interfered with the facilitation after treatment (Keane & Kiran, 2015); When generalization is only observed in semantically-related translations, there may be some form of cross-language inhibition that does not impact the semantically-related items in the untreated language (Keane & Kiran, 2015). In addition, there has been neuroimaging evidence suggesting that bilinguals with damage in the language-control network showed cross-language interference from the trained to the untrained language (Abutalebi & Green, 2007; Abutalebi et al., 2009).

The effect of cross-language generalization may depend on a combination of factors, including the type of therapy approach, pre-morbid language proficiency, and the linguistic distance between languages (Ansaldo & Saidi, 2014; Kohnert, 2009). Cross-language generalization has been frequently reported in previous studies implementing semantic-based treatment approaches (Croft et al., 2011; Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Iakupova, 2011; Kiran & Roberts, 2010). Given that lexical-semantic connections between L1 and L2 are linked via a shared semantic system (de Groot, 1992; Francis, 2005; Kroll & Stewart, 1994), activation of semantic representations should flow to both L1 and

L2 lexicons (Costa et al., 2006; Hermans et al., 1998). Thus, treatment approaches based on lexical-semantic models have the potential for cross-language generalization via spreading activation from the shared semantic system to the target phonological representations in both treated and untreated languages (Kohnert, 2009).

Patterns of cross-language generalization also depend on language proficiency or language dominance in BWA. Previous studies have reported greater cross-language generalization when treatment targeted the less dominant language (L2) in unbalanced bilinguals (Ansaldo & Saidi, 2014; Faroqi-Shah et al., 2010; Edmonds & Kiran, 2006). These findings substantiate the RHM (Kroll & Stewart, 1994), which predicts that the connections between the semantic system and both L1 and L2 lexicons differ in their strengths as a function of proficiency. Specifically, connections between the semantic system and L1 are assumed to be stronger than connections between the semantic system and L2 in unbalanced bilinguals. Hence, targeting the less dominant language should strengthen the connection from L2 to L1, leading to a cross-language generalization. In balanced bilinguals, the effect of cross-language generalization has been reported regardless of the treatment language (Kohnert, 2009; Li et al., 2020). This finding supports the *Distributed Feature Model* (de Groot, 1992), which posits that connections between the semantic system and both lexicons and between L1 and L2 lexicons are equally strong in balanced bilinguals. Thus, training in either language in balanced bilinguals should facilitate cross-language generalization.

The linguistic distance further plays a role in the effect of cross-language generalization (Ansaldo & Saidi, 2014). Most studies have found cross-language generalization in bilinguals speaking typologically similar languages, i.e., Spanish-English (Goral et al., 2010; Kohnert, 2004; Kurland & Falcon, 2011). Cognates are one form of measuring linguistic similarities (Kuzmina et al., 2019). When languages contain many cognates, such as Spanish and Catalan, linguistic distance is relatively smaller as compared to languages without cognates, such as Spanish and Mandarin. Previous studies have identified cross-language generalization after training cognates rather than noncognates in BWA. For example, a case study found a cross-language generalization in a Spanish-English BWA when training cognates in L1 (Spanish), suggesting that cognates facilitate this generalization in BWA (Kohnert, 2004; see next section for study details). Nevertheless, fewer studies have examined cross-language generalization in bilinguals speaking typologically different languages. Li et al. (2020) investigated the effect of Verb Network Strengthening Treatment (VNeST; Edmonds et al., 2009) in two Mandarin-English BWA who were both trained in their L1, i.e., Mandarin. Results showed a significant improvement in naming verbs in the untrained language, i.e., English, suggesting that small linguistic distance may not be a prerequisite for cross-language generalization (Kuzmina et al., 2019).

In sum, findings from previous studies in bilingual aphasia treatment indicate a strong treatment acquisition effect irrespective of the target language. But in terms of generalizations, evidence suggests an overall benefit of semantic-based treatment approaches. Although cross-language generalization depends on a combination of factors, training in L2 of unbalanced bilinguals or in either language of balanced bilinguals has shown favorable generalization effects. Since the largest body of research in bilingual aphasia rehabilitation has been conducted in individuals speaking Indo-European languages, it is imperative for future studies to examine the treatment efficacy and efficiency in bilinguals speaking typologically dissimilar languages (e.g., Mandarin-English BWA).

2.3.2 Bilingual aphasia treatment for nouns and verbs

In this section, semantic-based treatment targeting verbs and nouns in BWA will be reviewed (Table 2.2). Current evidence of the treatment efficacy in BWA has been largely restricted to nouns, and whether similar patterns of treatment-induced language recovery emerge in verb treatment remains unclear. Treatment targeting nouns and verbs will be first discussed separately, followed by a description of a few treatment studies that have targeted both grammatical categories.

2.3.2.1 Bilingual aphasia treatment in nouns

Previous studies implementing semantic-based treatment have consistently reported a positive treatment gain. One well-established treatment approach is Semantic Feature Analysis (SFA; Boyle & Coelho, 1995; Boyle, 2004; Coelho et al., 2000), which aims to improve the accuracy of lexical retrieval through strengthening the semantic network. In SFA, participants are typically asked to generate or verify semantic features of the target item centered around six category labels: "function," "characteristics," "physical attributes," "category," "location," and "associated objects" (Figure 2.1). Overall, monolingual studies using SFA have revealed three patterns of findings: (1) robust treatment gain, (2) inconsistent generalizations to untrained nouns, and (3) limited generalization to sentences or connected speech (Efstratiadou et al., 2018; Gravier et al., 2018; Quique et al., 2019).

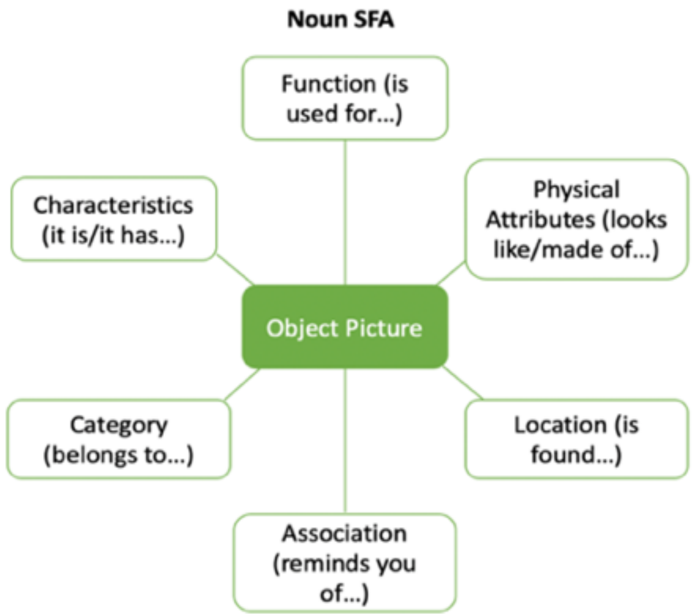

Figure 2.1. Semantic Feature Analysis for nouns.

Kiran and colleagues (Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Iakupova, 2011; Kiran & Roberts, 2010) have further modified the SFA protocol for use in BWA (Table 2.2). Many of these previous studies have examined treatment acquisition effects, as well as within- and cross-language generalization effects in BWA with a variety of language combinations, including Spanish-English (Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Roberts, 2010), French-English (Kiran & Roberts, 2010), Russian-English (Kiran & Iakupova, 2011), and Kannada-English (Krishnan et al., 2014).

Edmonds and Kiran (2006) adapted SFA treatment in three English-Spanish BWA (P1: balanced; P2 & P3: English-dominant), and naming accuracy was assessed for both trained and untrained items. All participants showed significant improvement in naming the trained items. P1 further showed within- and cross-language generalizations following treatment in Spanish; P2 demonstrated within-language generalization but not cross-language generalization following treatment in English, and only cross-language generalization following treatment in Spanish; and P3 showed cross-language generalization but not within-language generalization after treatment in Spanish. These results suggest that treatment targeting the dominant language promotes within-language generalization, and treatment targeting the less dominant language facilitates cross-language generalization in unbalanced BWA. In balanced BWA, training in either L1 or L2 enables both types of generalization.

Kiran and Roberts (2010) investigated the effect of SFA targeting noun retrieval in two Spanish-English and two French-English BWA. Therapy began with one set of items in one language, which was shifted to the semantically-related set in the other language if treatment gains did not reach 80% accuracy after 20 sessions. All participants showed significant improvement in naming the trained nouns in the treated language. Generalization to semantically-related items was reported in both Spanish-English BWA and one French-English BWA. Further, cross-language generalizations in both trained and untrained items were observed in one French-English BWA.

Previous studies of SFA have been further replicated in one Russian-English BWA, who received treatment in L2, i.e., English (Kiran & Iakupova, 2011). This participant showed remarkable improvement in naming the trained and untrained items by achieving 100% accuracy. Additionally, scores on the English and Russian BATs also increased significantly post-treatment, suggesting an overall improvement in the trained language and generalization to the untrained language.

Kiran et al. (2013) investigated the effect of SFA treatment in 17 Spanish-English BWA who were trained in either of their languages. Results showed a significant improvement in naming the trained items in 14/17 patients. Among these participants, three also showed within- and cross-language generalizations; five showed only within-language generalization; two exhibited cross-language generalization to only translations of the trained items; and three showed within-language generalization and cross-language generalization to translations of semantically-related items. The other four participants did not show any patterns of generalization. These findings suggest an interplay between facilitation and inhibition in bilingual aphasia recovery.

Croft et al. (2011) examined the effects of semantic and phonological naming treatment in five Bengali-English BWA, in which all but one rated Bengali as the dominant language. Participants underwent two phases of therapy targeting each of their languages. Half of each treatment session targeted semantics, and the other half targeted phonology. Two BWA showed significant improvement in the trained items following semantic treatment in either Bengali or English. Four BWA improved significantly in the trained items after phonological treatment in Bengali, and three improved in the trained items following phonological treatment in English. Cross-language generalization in the dominant language was further observed in three BWA after semantic therapy. These results suggest that semantic-based treatment benefits naming of the trained items and facilitates generalization to the untreated language. However, this study did not control for treatment approaches so that the treatment effect could be confounded by one another.

Another study evaluated treatment effects for cognates and non-cognates by targeting lexical-semantic skills in a Spanish-English BWA (Kohnert, 2004). This treatment did not specifically implement SFA but instead included activities such as picture identification, picture-word matching, semantic association generation, cloze tasks, writing to dictation, and confrontation naming. The results revealed significant gains in both trained and untrained cognates and non-cognates. Cross-language generalization was also observed from Spanish to English in only cognates. These findings further confirm that semantic-based treatment promotes treatment efficacy and efficiency in bilinguals with lexical retrieval difficulties.

These previous studies have implemented semantic-based treatment targeting noun retrieval in bilinguals with different language combinations. Altogether, findings from these studies indicate a direct treatment gain after semantic-based treatment and generalizations to semantically-related untrained items. Although patterns of cross-language generalization are mixed, evidence suggests that training in the less dominant language of an unbalanced bilingual or in either L1 or L2 of a balanced bilingual facilitates this generalization. These results underscore the robust effects of semantic-based intervention in BWA.

2.3.2.2 Bilingual aphasia treatment in verbs

Training verb retrieval is equally important in bilingual aphasia rehabilitation as verbs play a critical role in sentence formulation. However, few studies have attempted to examine the effect of verb treatment, particularly in BWA. The largest body of research in verb treatment has been conducted on monolinguals with aphasia using treatment approaches targeting lexical retrieval at the single-word level (Raymer & Kohen, 2006;

Wambaugh et al., 2014; Wambaugh & Ferguson, 2007) or in a sentence context (Bastiaanse et al., 2006; Conroy et al., 2009; Edmonds et al., 2009, 2014; Edwards & Tucker, 2006; Webster & Whitworth, 2012). There are three main findings across these treatment studies in monolinguals with aphasia: (1) consistent treatment acquisition effect in the trained verbs; (2) inconsistent generalization to the untrained verbs, and (3) inconsistent findings of generalization to sentences or discourse production (Edmonds et al., 2009, 2014; Edmonds & Babb, 2011; Marshall et al., 1998; Mcneil et al., 1997; Raymer & Ellsworth, 2002; Wambaugh et al., 2014; Wambaugh & Ferguson, 2007; Webster & Whitworth, 2012). These mixed patterns of generalizations can be attributed to different outcome measures across studies, co-occurring sentence level deficits, and the type of treatment approach (Webster & Whitworth, 2012).

Relatively fewer studies so far have investigated the effect of treatment targeting verbs in BWA, and evidence has been limited to single-case studies or case series (Ansaldo et al., 2010; Goral et al., 2012; Knoph et al., 2015, 2017; Lerman et al., 2019; Li et al., 2020; see Table 2.2 for a summary). These studies have included a variety of bilingual populations speaking Spanish-English (Anasaldo et al., 2010), Hebrew-English (Lerman et al., 2019), Arabic-English (Knoph, 2013), and Mandarin-English (Li et al., 2020). Similar to monolinguals with aphasia, these bilingual studies have also revealed remarkable gains in the trained verbs. Nevertheless, some but not all studies have reported within-language generalization to semantically-related words (Knoph et al., 2017; Lerman et al., 2019; Li et al., 2020).

Effects of cross-language generalization have also been examined among previous bilingual treatment studies targeting verbs. Although patterns of this generalization are mixed, evidence mirrors that of bilingual noun treatment in two ways. First, semantic-based treatment promotes cross-language generalization given that spreading activation from the shared semantic system facilitates lexical retrieval in both languages (de Groot, 1992; Kohnert, 2009; Kroll & Stewart, 1994). Treatment targeting semantic-conceptual processing can also compensate for lexical processing deficits as patients with impaired verb-retrieval ability may rely on their preserved semantic-conceptual system (Dresang et al., 2021). Second, cross-language generalization is frequently observed following treatment targeting the less dominant language, especially in unbalanced bilinguals (Ansaldo et al., 2010; Goral et al., 2012; Knoph et al., 2017; Lerman et al., 2019).

To date, two semantic-based treatment approaches have been adapted in BWA to target verb-retrieval difficulty, one is VNeST (Edmonds et al., 2009; Lerman et al., 2019; Li et al., 2020), and the other is SFA (Ansaldo et al., 2010; Goral et al., 2012; Knoph et al., 2015, 2017). In general, these approaches have shown robust evidence of treatment effects, as reviewed below.

VNeST

VNeST aims to improve verb retrieval ability in a sentence context for individuals with aphasia (Edmonds, 2016; Edmonds et al., 2009, 2014). Participants are required to generate explicit thematic roles associated with a trained verb for diverse event schemas, so that the semantic network can be strengthened to activate the target word forms (Dell et al., 1997; Edmonds & Babb, 2011). Evidence of VNeST has been mostly derived from monolinguals with aphasia (Edmonds et al., 2014; Edmonds & Babb, 2011). These studies have shown positive treatment gains in the trained items and noticeable generalizations to the untrained verbs. Some of these studies have also revealed generalizations to sentence and discourse production, in which the integration of cognitive, micro-linguistic, and macro-linguistic skills is often required (Edmonds et al., 2009; Edmonds et al., 2014). These findings substantiate the robust treatment effects of VNeST in individuals with verb-retrieval deficits.

Three single-subject design studies have adapted VNeST in BWA (Lerman et al., 2019, 2020; Li et al., 2020). In the first study, Lerman et al. (2019) investigated generalization to discourse production in a Hebrew-English bilingual with agrammatic aphasia, who was trained in the post-morbidly less proficient language, i.e., English. Results showed a significant improvement in lexical retrieval of nouns and verbs in the treated language in picture naming and sentence production. Discourse analysis revealed a larger improvement in the untreated versus treated language. These findings suggest that training in the less proficient language of an unbalanced BWA promotes cross-language generalization in discourse production even if there is no generalization to single-word naming and sentence production in that language.

The second study investigated treatment effects of VNeST in three English (L1) – Hebrew (L2) BWA (Lerman et al., 2020), who underwent two sequential treatment phases, one for each language. The results showed consistent treatment gains across all three BWA after each treatment phase. Additionally, significant within-language improvements in single-word retrieval, sentences, oral connected speech, and written narratives were observed following treatment in their post-morbidly less dominant language. Finally, one participant showed significant cross-language generalization following treatment in the more impaired language. The other two BWA exhibited improvement in the untreated language after training in the less impaired language. These findings suggest promising treatment effects of VNeST in BWA.

The VNeST protocol has recently been extended to two Mandarin-English BWA (Li et al., 2020), who received treatment in their L1 (Mandarin). Both participants showed significant improvement in naming the trained verbs and modest generalizations to semantically-related untrained verbs. Patterns of cross-language generalization were also identified in the untreated language, but varied between participants. These BWA additionally demonstrated mixed patterns of improvement in connected speech based on measures of complete utterances (CUs; Edmonds et al., 2009) and correct information units (CIUs; Nicholas & Brookshire, 1993). Further, widespread generalizations beyond the trained items were observed in other standardized assessments such as the Boston Naming Test (BNT; Kaplan et al., 2001) and the Verb Naming Test (VNT) of the Northwestern Assessment of Verbs and Sentences (NAVS, Thompson, 2012). This study is the first to target verb retrieval in Mandarin-English BWA. Findings from this study suggest that semantic-based treatment is effective in bilinguals speaking linguistically distant languages.

Verb SFA

Another semantic-based treatment approach that has been used for verb therapy is SFA (Wambaugh et al., 2014; Wambaugh & Ferguson, 2007). Similar to the noun SFA, this approach involves generating or verifying semantic features related to the target verb, leading to activations of its semantic network and phonological retrieval (Boyle & Coelho, 1995). Additionally, this approach can improve the semantically-related untrained verbs by stimulating the semantic network and developing a feature generation strategy (Boyle, 2004; Boyle & Coelho, 1995). Effects of verb SFA have been previously validated in five monolinguals with anomic aphasia (Wambaugh et al., 2014; Wambaugh & Ferguson, 2007). In these studies, participants were asked to generate features for the target verb based on six category labels: "subject," "purpose/object of action," "part of body or tool used to act the action," "description," "location" and "associated objects or actions" (Wambaugh & Ferguson, 2007; Figure 2.2). Thematic roles (i.e., patient, agent) are included in feature categories given the potential for bidirectional activation between verbs and their thematic roles (McRae et al., 2005). Most of the five participants showed improvement in naming the trained verbs (Wambaugh & Ferguson, 2007; Wambaugh et al., 2014). Gains in discourse production were also reported in some participants, as evidenced by increased production of CIUs (Nicholas & Brookshire, 1993) and narrative words. However, none of the participants showed improvement in naming the untrained verbs, possibly because the SFA treatment was initially designed to increase the amount of semantically relevant information conveyed instead of the naming accuracy (Massaro & Tompkins, 1994).

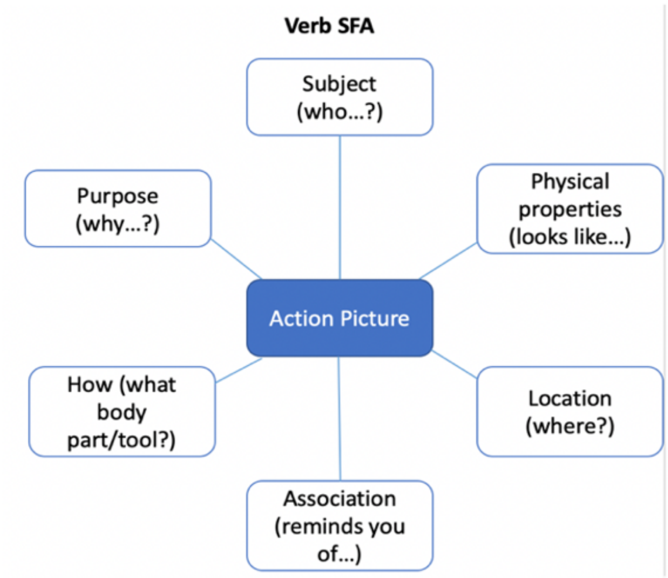

Figure 2.2. Semantic Feature Analysis for verbs.

Two studies have further attempted to implement SFA for verbs in bi/multilinguals with aphasia (Knoph et al., 2015, 2017), but evidence has been restricted to three individuals. In the first study, two different treatment protocols (i.e., communication-based therapy and SFA) were administered sequentially to a Portuguese-Ronga-Norwegian trilingual with aphasia and an English-Norwegian BWA (Knoph et al., 2017). Both individuals received treatment in Norwegian, the post-stroke less proficient language. Following the verb SFA, there was a significant improvement in naming the trained verbs in both participants and a generalization to Portuguese in the trilingual patient. Further, there was a noticeable gain in narrative production in both treated and untreated languages in both participants. Another study investigated the effect of verb SFA at the word and the discourse level in a Japanese-English-German-Norwegian multilingual with aphasia (Knoph et al., 2015). This participant received a verb SFA in Norwegian, the less proficient language. Results showed a significant improvement in naming the trained verbs in

Norwegian and items in the untreated language, German. There were further generalizations to narrative production in the treated language as well as in English and German. Findings from these two studies suggest that SFA has the benefit of improving verb retrieval ability in bi/multilinguals with aphasia. Consistent with noun SFA, evidence from verb SFA studies corroborates that targeting the less dominant language can potentially maximize the cross-language generalization. These findings further indicate a trend of generalization beyond the single-word level, suggesting an advantage of adapting SFA targeting verb retrieval. However, neither of the previous studies found a significant improvement in the untrained verbs, possibly because the trained and untrained items were not semantically related.

Previous studies have suggested that semantic-based treatment targeting either nouns or verbs promotes treatment gains in BWA. Nevertheless, to what extent treatment and generalization effects are similar in training nouns and verbs is unknown. Therefore, it is essential to compare treatment effects between training nouns and verbs in BWA and examine whether patterns of treatment-induced language recovery differ by a specific grammatical category.

2.3.2.3 Bilingual aphasia treatment comparing verbs and nouns

Three treatment studies have targeted both verbs and nouns in bi/multilinguals with aphasia (Ansaldo et al., 2010; Goral et al., 2012; Miertsch et al., 2009; see Table 2.2 for a summary). The first study targeted lexical-semantic processing in L3 (French) of a German-English-French trilingual with aphasia (Miertsch et al., 2009). Therapy focused on word-finding difficulties of verbs and nouns via exercises with prepositions, semantic-conceptual relationships between words, and word retrieval in discourse. The participant demonstrated a significant improvement in lexical production in French and English based on the BAT (Paradis, 1987). However, lexical retrieval of verbs and nouns was not directly compared.

The second study targeted verb and noun retrieval in a Spanish-German-French-English multilingual with aphasia (Goral et al., 2012), who underwent two phases of treatment, one in the highly proficient language (Spanish) and another in the least proficient language (English). A combination of approaches was implemented for therapy, including SFA, sentence generation, and rapid naming. There were significant gains in lexical retrieval of verbs and nouns in English, German and French in various standardized language tasks following treatment in English. After treatment in Spanish, the number of words significantly increased in French and English verbal tasks. Nevertheless, although both verbs and nouns were included in treatment, patterns of language impairment and treatment-induced changes were not assessed as a function of grammatical category. Hence, whether similar patterns of language recovery emerged following verb and noun treatment is unknown, an important aspect of the current project.

The third study aimed to examine the effect of a model-based intervention in bilinguals with pathological switching (Ansaldo et al., 2010). This study implemented *switching back through translation* (SBTT) with SFA to improve naming ability in a Spanish-English BWA. SBTT aimed to overcome involuntary pathological switching by asking the patient to translate the word in the non-target language into the target language. Hence, this allowed the individual to bypass disrupted external suppression mechanisms (inhibition) and trigger preserved internal suppression devices (translation) to facilitate word retrieval. Lexical retrieval of both trained and untrained (control) items was assessed in a picture naming task. Before treatment, the participant showed better naming of nouns than verbs in the treated language (Spanish) and better naming of verbs than nouns in the untreated language (English). Cross-linguistically, access to nouns was significantly more impaired in English than in Spanish, but no such difference was reported for verbs. The post-treatment results revealed significant improvement of verbs and nouns in the treated language but no generalizations to the untrained items or the untreated language. The pre-treatment "verb advantage" in English had diminished after treatment. The cross-linguistic verb-noun dissociation before therapy was possibly attributed to late L2 acquisition. Nevertheless, this study did not examine the effect of grammatical category on treatment gains, as will be addressed in the current project. Further, evidence is limited to one BWA, so it is difficult to conclude whether treatment gains resulted from SBTT, SFA, or both approaches.

Table 2.2. Summary of semantic-based treatment studies for nouns and verbs in bi/multilinguals with aphasia.

Study	Participants	Proficiency	Verb or Noun	Type of Tx	Lang of Tx	Direct Tx effect	Within-lang Gen	Cross-lang Gen	Gen beyond single-word
Noun treatment									
Edmonds & Kiran (2006)	3 English-Spanish BWA	P1: L1 (English) = L2 (Spanish); P2 & P3 (simultaneous bilinguals): English > Spanish	Noun	SFA	P1: L2; P2: English then Spanish; P3: Spanish	Y	Y	Y	N/A
Kiran & Roberts (2010)	P1 & P2: Spanish (L1)-English (L2); P3 & P4: French (L1)-English (L2) BWA	P1: L2 > L1; P2: L1 = L2; P3: L1 > L2; P4: L1 = L2	Noun	SFA	L1 for P1; Both for P2 - P4	Y	Y	Y	N/A
Kiran & Iakupova (2011)	2 Russian (L1)-English (L2) BWA (only one was enrolled in treatment)	L1 > L2	Noun	SFA	L2	Y	Y	Y	N/A
Kiran et al. (2013)	17 Spanish-English	Various profiles	Noun	SFA	L1 or L2	Y	Y	Y	N/A
Croft et al. (2011)	5 Bengali (L1) - English (L2) BWA	L1 > L2 (n = 4); L2 > L1 (n = 1)	Noun	Multiple tasks targeting semantics and phonology	Both	Y	N	Y	N/A
Kohnert et al. (2004)	1 Spanish (L1)-English (L2) BWA	L1 = L2	Noun	Multiple tasks targeting lexical-semantic skills	Both	Y	Y	Y	N/A
Verb Treatment									
Lerman et al. (2019)	1 Hebrew (L1)-English (L2) bilingual with post-stroke aphasia	L1 > L2	Verb	VNeST	L2	Y	N/A	N	Y

Lerman et al. (2020)	3 English (L1)-Hebrew (L2) BWA	L1 = L2	Verb	VNeST	Both	Y	Y	Y	Y
Li et al. (2020)	2 Mandarin (L1)-English (L2) bilinguals with post-stroke aphasia	L1 = L2	Verb	VNeST	L1	Y	Y	Y	Y
Knoph et al. (2015)	1 Japanese (L1) -English (L2) -German (L3) -Norwegian (L4)	L1 = L2 = L4 > L3	Verb	SFA	L4	Y	N	Y	Y
Knoph et al. (2017)	P1: Portuguese (L1)-Ronga (L1)-Norwegian (L2), P2: English (L1)-Norwegian (L2)	L1 > L2	Verb	CBT and SFA	L2	Y	N	Y	Y
Treatment including both verbs and nouns									
Miertsch et al. (2009)	1 German (L1)-English (L2)-French (L3)	L1 = L2 = L3	Both	Lexical-semantic training	L3	Y (assessed using the BAT)	N/A	Y	N/a
Goral et al. (2012)	1 Spanish (L1)-French (L2)-German (L3)-English (L3) multilingual with aphasia	Spanish > French/German > English	Both	SFA, sentence generation, rapid naming	L1 then L3	Y	Y	Y	Y
Ansaldo et al. (2010)	1 Spanish (L1)-English (L2) BWA	L1 = L2	Both	SBTT & SFA	L1	Y	N	N	N/a

Note: Studies are presented in the same sequence as reviewed in-text. L1: first language, L2: second language, L3: third language, L4: forth language; P1 – P4: patients 1 – 4; Tx: treatment; Gen: generalization; SFA: Semantic Feature Analysis; VNeST: Verb Network Strengthening Treatment; CBT: communication-based therapy; SBTT: switch back through translation; BAT: Bilingual Aphasia Test; Y: yes; N: No; N/A: not available.

In sum, many studies have adapted treatment approaches targeting either nouns or verbs in BWA. Positive treatment gains have been consistently reported irrespective of the target category. In comparison, recovery patterns are more complex in generalizations to untrained items, untreated language, and beyond the word level. Semantic-based treatment approaches (i.e., SFA, VNeST) are well-positioned to promote within- and cross-language generalizations in BWA. Although patterns of cross-language generalization are mixed across studies, training in the less dominant language in unbalanced BWA or in either language in balanced BWA can promote this generalization.

Collectively, these trends highlight the efficacy and efficiency of aphasia treatment targeting verbs and nouns in BWA. Yet, most of these studies have focused on training either grammatical category, with very little evidence of whether verbs and nouns benefit from the same treatment approach to a similar extent. Hence, it is important to directly compare treatment effects between verbs and nouns in BWA to help better understand whether treatment effects differ by a specific grammatical category. Three studies have targeted both verbs and nouns in treatment with small sample sizes (Ansaldo et al., 2010; Goral et al., 2012; Miertsch et al., 2009), but none of them have directly compared treatment effects between these two grammatical categories. To investigate whether verbs and nouns show similar recovery patterns, the same treatment steps need to be implemented to examine treatment effects as a function of grammatical category. Hence, the current project aimed to extend semantic-based treatment to a sample of 12 Mandarin-English BWA and examine patterns of language impairment and treatment-induced language recovery between verbs and nouns.

3. RATIONALE, AIMS, AND HYPOTHESES

As discussed previously, the patterns of lexical-retrieval impairment in individuals with aphasia may depend on a specific grammatical category. Investigating lexical retrieval of different word categories in BWA would shed light on bilingual language recovery. In previous bilingual aphasia studies, a verb-noun dissociation has been identified in single-word naming, i.e., lower naming accuracy for verbs than nouns. This pattern of lexical impairment is overall similar in L1 and L2, yet the evidence has been restricted to individuals speaking typologically similar languages. In addition, knowing whether similar patterns emerge beyond the word level (i.e., in discourse production) would help identify linguistic markers for bilingual language recovery. In bilingual aphasia rehabilitation, studies implementing semantic-based treatment have reported a positive treatment gain with mixed patterns of generalizations. Yet, the bulk of the evidence has come from noun treatment, and to what extent patterns of language recovery are similar in both noun and verb treatment is unclear. Most research in bilingual aphasia recovery and language rehabilitation has been limited to Indo-European languages (i.e., Spanish-English). With the growing Chinese-speaking bilingual population in the U.S., future research needs to establish the evidence base for language rehabilitation in this population. Hence, the current project aimed to investigate patterns of lexical impairment and treatment-induced language recovery between verbs and nouns in Mandarin-English BWA in the context of sequential treatment cycles, one for nouns and one for verbs. The primary goals of the project included directly comparing: (1) lexical retrieval between nouns and verbs in both single-word naming and discourse production (Study 1), and (2) patterns of treatment-induced language recovery between training nouns and verbs via the implementation of the same treatment steps for both grammatical categories (Study 2).

The overarching hypothesis for this dissertation is that patterns of lexical retrieval and treatment-induced language recovery should be different between nouns and verbs in Mandarin-English BWA. Study 1 aimed to address the first aspect of this hypothesis by directly comparing lexical retrieval of nouns and verbs via thorough assessments of single-word naming and discourse production. Study 2 addressed the second aspect of this hypothesis by implementing a semantic-based treatment with the same treatment steps targeting both nouns and verbs.

3.1 Study 1: To what extent does a verb and noun dissociation emerge at the *single-word* and *discourse* levels in Mandarin-English BWA?

The primary goal of Study 1 was to examine patterns of noun and verb retrieval by assessing single-word naming and discourse production in both languages of Mandarin-English BWA. According to previous research in BWA (Faroqi-Shah & Wakes, 2010; Kambanaros & van Steenbrugge, 2006; Kambanaros, 2010a; Poncelet et al., 2007), it was hypothesized that Mandarin-English BWA would demonstrate more difficulty with verb retrieval relative to noun retrieval in both single-word naming and discourse production. This pattern of lexical impairment would also be similar in L1 and L2. Alternatively, the verb-noun dissociation would only emerge in English but not in Mandarin given that verbs in English carry richer morphosyntactic structures than verbs in Mandarin, leading to a breakdown in morphological inflections of verbs at the lemma level (Shapiro et al., 2000; Tsapkini et al., 2002). Findings from this study would provide evidence of lexical impairment in Mandarin-English BWA and help identify potential linguistic markers of language recovery for this bilingual population.

3.2 Study 2: To what extent do differences in treatment effects emerge between training nouns and verbs in Mandarin-English BWA?

Prior research in bilingual aphasia rehabilitation has mostly focused on noun treatment, whereas little evidence exists for verb treatment. The primary goal of Study 2 was to investigate whether training nouns and verbs would show differences in treatment and generalization effects by implementing the same treatment steps targeting nouns or verbs. Treatment effects were captured via measures of (1) direct treatment gain, (2) within-language generalization (i.e., generalization to semantically-related items), (3) cross-language generalization (i.e., generalization to the untreated language), (4) generalization to sentence and discourse production, and (5) generalization to untrained naming tasks. For both noun and verb treatment, it was hypothesized that Mandarin-English BWA would show significant improvement in naming the trained and semantically-related untrained items in both treated and untreated languages (Kiran & Bassetto, 2008; Collins & Loftus, 1975; Costa et al., 2006; de Bot, 1992). These patterns of language recovery should not be mediated by a specific grammatical category, as previous studies have shown positive treatment effects targeting either nouns or verbs (Edmonds & Kiran, 2006; Kiran et al., 2013; Lerman et al., 2019; Li et al., 2020). Alternatively, training verbs was hypothesized to show more improvement than training nouns. Since verbs have weaker connections at the semantic representation level than nouns (Gentner, 1981; Vigliocco et al., 2011), targeting the semantic network in verb treatment would enhance lexical access to a larger extent than in noun treatment.

It was also predicted that Mandarin-English BWA would show significant generalizations to sentence and discourse production, particularly following verb treatment since previous verb treatment studies have reported significant generalization effects in bi/multilinguals with aphasia (Knoph et al., 2015, 2017; Lerman et al., 2019; Li et al., 2020). In addition, there has been evidence suggesting a priming effect from verbs to their thematic roles (Ferretti et al., 2001; McRae et al., 2005), so training verbs was hypothesized to facilitate priming or activation of nouns that are associated with thematic roles, leading to increased production of complete utterances. The alternative hypothesis was that training nouns and verbs would show similar generalization effect beyond the word-level, as prior research has pointed out that the priming effect between verbs and their thematic roles can be bidirectional (Ferretti et al., 2001; McRae et al., 2005). Hence, targeting either nouns or verbs would enhance lexical access to all syntactic structures, i.e., subject, verb, and object.

Finally, Mandarin-English BWA were hypothesized to show improvement in naming untrained objects and actions, as suggested by previous aphasia treatment studies (Lerman et al., 2019; Li et al., 2020). This generalization was expected to be greater following verb than noun treatment, given the aforementioned priming effect from verbs to their thematic roles (Ferretti et al., 2001; McRae et al., 2005). Alternatively, the magnitude of this generalization was expected to be similar following noun and verb treatment, as previous studies have pointed to better overall lexical retrieval following semantic-based treatment targeting either nouns or verbs (Gil & Goral, 2004; Knoph et al., 2015, 2017; Li et al., 2020). Altogether, findings from Study 2 would gain clinical evidence of language rehabilitation in Mandarin-English BWA.

4. NOUN AND VERB IMPAIRMENT IN SINGLE-WORD NAMING AND DISCOURSE PRODUCTION IN MANDARIN-ENGLISH BILINGUALS WITH APHASIA

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Li, R., & Kiran, S. (2022). Noun and Verb Impairment in Single-Word Naming and Discourse Production in Mandarin-English Bilinguals with Aphasia. *Aphasiology*.

4.1 Background

The growing bilingual population coincides with an overall increase of older people at risk for neurogenic disorders, i.e., stroke and dementia (Hoeffel et al., 2012). In bilinguals, aphasia may occur in one or both languages and demonstrate diverse patterns of language impairment due to complex cross-language interactions (Fabbro, 2001; Lorenzen & Murray, 2008; Paradis, 2001). Evidence of language recovery in bilinguals with aphasia (BWA) is mostly derived from individuals speaking Indo-European languages (e.g., Spanish-English). Given the increase in the number of Chinese-speaking individuals in the U.S. (Zeigler & Camarota, 2019), there is an urgent need for future research to uncover the patterns of language impairment in Chinese-English BWA.

Anomia, or trouble retrieving words and/or naming objects and actions, is a hallmark symptom in aphasia. Studying anomia in BWA enables a direct cross-linguistic comparison of language recovery patterns, and provides insight into models of both bilingual language processing and language impairment (Nadeau, 2019).

Lexical retrieval in individuals with aphasia can be differentially impacted based on specific grammatical class, i.e., nouns and verbs (Berndt et al., 1997; Kim & Thompson, 2000; Miceli et al., 1984; Zingeser & Berndt, 1990). Several studies so far have attempted to compare lexical-retrieval ability between nouns and verbs in BWA (Kremin & De

Agostini, 1995; Sasanuma & Park, 1995; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Faroqi-Shah & Waked, 2010; Kambanaros, 2010; Dai et al., 2012). Among these previous studies, some have reported no noticeable difference between verb and noun retrieval (Kremin & De Agostini, 1995; Sasanuma & Park, 1995), whereas others have found a verb-noun dissociation with higher accuracy for object naming when compared to action naming (Kambanaros, 2010; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007).

Different psycholinguistic accounts have been posited to explain the verb-noun dissociation in individuals with aphasia. Among many other lexical-semantic variables that may impact lexical processing (e.g., frequency, familiarity; Cuetos et al., 2002; Kemmerer & Tranel, 2000; Luzzatti et al., 2002), *imageability* has been identified as a strong predictor of verb and noun naming (Kambanaros, 2010b; Kiran & Tuchtenhagen, 2005; Luzzatti et al., 2002). In general, verbs are semantic/conceptually less imageable than nouns because verbs often denote abstract events and actions that are temporarily transient (Bird et al., 2003; Gentner, 2006; Vigliocco et al., 2011). This account has been corroborated by studies that did not find differences between nouns and verbs after imageability was controlled for (Bird et al., 2001; Shapiro & Caramazza, 2003). From a morphosyntactic standpoint, verbs in many languages carry rich morphosyntactic information in sentence production critical to conveying one's message (Vigliocco et al., 2011). For example, verbs in English may require thematic roles (i.e., agent, patient) assigned to each argument, making them more difficult to process than nouns (Ferretti et al., 2001). These accounts altogether inform us that the differences between verb and noun processing are an artifact of the many processing dimensions that separate these two grammatical categories (Szekely et al., 2005).

In addition to single-word processing, several studies in bi/multilinguals with aphasia have conducted spoken discourse analysis to investigate patterns of verb and noun production in connected speech (Dai et al., 2012; Faroqi-Shah & Waked, 2010; Kambanaros, 2007). One study examined verb and noun retrieval in picture naming and narrative speech in a high-proficiency Arabic-French-English trilingual patient (Faroqi-Shah & Waked, 2010). The patient showed remarkable impairment for verbs than nouns in both tasks, indicating a similar pattern of verb-noun processing regardless of the linguistic context. Another study investigated lexical retrieval in both naming and connected speech in 12 late Greek-English BWA (Kambanaros, 2007). Results also revealed a verb-noun dissociation in picture naming with lower accuracy for verbs than nouns. In contrast to Faroqi-Shah & Waked (2010), this study found that patients who had difficulty with action naming could retrieve verbs during connected speech, whereas those who could name objects had difficulty with noun production in connected speech, suggesting an inconsistent pattern of verb and noun impairment across different linguistic contexts. The third study examined verb and noun retrieval in a Cantonese-Mandarin BWA (Dai et al., 2012), who exhibited better naming of objects than actions only in Mandarin. Additionally, this study reported noticeable differences between naming and discourse production with few occurrences of word-finding difficulties in discourse. However, no direct comparison was carried out. Altogether, results from these studies are mixed regarding the verb and noun dissociation across linguistic contexts. These complex findings are likely due to the inconsistency in assessment, analysis, or individual variation (Linnik et al., 2016; Stark et al., 2021). Examining this relationship between naming and lexical retrieval in discourse in BWA would help identify linguistic indicators of bilingual language recovery.

Patterns of verb and noun retrieval in BWA provide further evidence of whether the impairment is language-dependent or not. Results from most bilingual studies have pointed to a trend of non-dependency, that is, the afore-mentioned verb-noun dissociation was observed in both first (L1) and second (L2) languages (Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Miozzo et al., 2010). Note that L2 language proficiency and age of acquisition (AoA) varied across these studies. Hence, the verb-noun dissociation may not arise from an unbalanced language proficiency between L1 and L2, but instead from the conceptual/linguistic properties that differ between grammatical categories (i.e., difficulty accessing the semantic or morphological representation of verbs; Kambanaros, 2010). Additionally, the evidence of a verb-noun dissociation has been limited to Indo-European languages, many of which carry complex morphosyntactic structures. However, there is a lack of evidence whether a similar pattern of impairment is observed in bilinguals speaking typologically different languages, i.e., Chinese-English. Verbs in some languages are morphosyntactically not as complex as verbs in other languages. For instance, Chinese is a “verb-friendly” language in which verbs carry less morphosyntactic information relative to verbs in English (Gentner, 1981). Therefore, one would assume that the pattern of verb and noun impairment might be different in these two languages, which can be uncovered in Chinese-English BWA.

In sum, while most previous studies have identified a verb and noun dissociation in single-word naming, whether a similar pattern of this dissociation exists across different linguistic contexts remains unclear. Patterns of verb and noun retrieval in BWA may arise from a complex interaction among factors including the conceptual and linguistic properties of grammatical categories, cross-linguistic characteristics, and individual heterogeneity (Kambanaros, 2010b). In BWA, a similar pattern of verb-noun impairment in L1 and L2 has been consistently reported regardless of premorbid language proficiency. This finding suggests that the verb-noun dissociation primarily arises from the semantic representation level, which is shared between L1 and L2 in bilingual lexical processing (Kambanaros, 2010b). Nevertheless, evidence so far has been limited to languages that are typologically similar. It is therefore important to investigate verb and noun impairment in typologically dissimilar languages, i.e., Chinese-English, and thereby to better understand patterns of lexical impairment in BWA.

4.2 The current study

This study aimed to investigate patterns of verb and noun impairment in both naming and discourse production in Mandarin-English BWA. Specifically, we addressed the following research questions:

1) To what extent does a verb and noun dissociation emerge at the *single-word* level in Mandarin-English BWA?
2) To what extent does a verb and noun dissociation emerge at the *discourse* level in Mandarin-English BWA?
3) To what extent does a similar pattern of verb and noun dissociation emerge across single-word naming and discourse production in Mandarin-English BWA?

According to more recent bilingual studies that directly compared verb and noun retrieval in naming tasks (Kambanaros, 2010b; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007), it was hypothesized that Mandarin-English BWA would show a verb-noun dissociation with lower naming accuracy for verbs than nouns in both L1 and L2. Alternatively, the verb-noun dissociation may only be observed in the language that carries richer morphosyntactic structures than nouns (i.e., English). Additionally, we expected a verb-noun dissociation in discourse (Faroqi-Shah & Waked, 2010) and that naming performance of nouns and verbs would mirror the performance of lexical retrieval in discourse. An alternative hypothesis was that there would be no specific verb impairment in discourse tasks (Dai et al., 2012; Kambanaros, 2007), i.e., the pattern of verb and noun impairment is dissimilar across linguistic contexts in Mandarin-English BWA.

4.3 Methods

4.3.1 Participants

Twelve Mandarin-English bilinguals with chronic aphasia (11 due to left-hemisphere single stroke, 1 due to traumatic brain injury) were enrolled in the current study (Table 4.1; 6 females, L1 = Mandarin, mean age = 52.6 ± 18.5 years, mean years of education = 17.7 ± 3.4, mean months post-onset = 51.4 ± 48.4). These individuals met the following inclusion criteria: (1) frequently used Mandarin and English before onset, (2) diagnosed with aphasia based on the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007) for English and the Aphasia Battery in Chinese (ABC; Gao, 1993, 1996) for Mandarin, (3) were between 18 and 85 years old, (4) presented with normal/near normal or corrected-to-normal hearing and vision, (5) were premorbid right-handed, and (6) had no other neurological condition (i.e., dementia) or learning disorders. Participants were recruited from rehabilitation centers and hospitals around Boston as well as remotely from other places in the U.S. All enrolled participants were consented according to the Boston University Institutional Review Board (IRB) protocol.

Individual differences in lexical processing can be influenced by developmental and contextual factors such as L2 AoA, the degree of life-time exposure and the frequency of use in each language (Kastenbaum et al., 2019). Therefore, information about second language acquisition and language proficiency of each language was collected via the Language Use Questionnaire (LUQ; Kastenbaum et al., 2019; Table 4.1).

Table 4.1. Demographics and language use background.

ID	Sex	Age	Edu (yr)	MPO	AoA	Usage %		Exposure %		LAR %	
						L1	L2	L1	L2	L1	L2
P1	F	75.2	18.0	110.8	16.0	4.4	95.6	32.9	67.1	100.0	100.0
P2	M	72.7	20.0	165.2	10.0	33.4	66.6	19.5	80.5	100.0	100.0
P3	M	31.5	25.0	45.0	10.0	43.9	56.1	63.3	36.7	100.0	80.0
[a]P4	F	29.3	17.0	19.2	8.0	0.0	100.0	39.2	60.8	100.0	100.0
P5	F	67.9	13.0	20.8	17.0	22.5	77.5	47.0	53.0	100.0	68.6
P6	F	25.2	20.0	8.2	9.0	56.6	43.4	74.1	25.9	100.0	68.6
P7	M	57.9	20.0	77.3	10.0	19.5	80.5	70.7	29.3	100.0	80.0
P8	M	42.8	16.0	17.4	12.0	50.0	50.0	80.2	19.8	100.0	60.0
P9	F	61.7	19.0	75.5	13.0	36.9	63.1	50.9	49.1	100.0	100.0
P10	F	53.0	15.0	20.5	12.0	29.2	70.8	43.6	56.4	88.6	82.9
P11	M	38.7	16.0	50.1	12.0	32.0	68.0	23.1	76.9	90.0	100.0
P12	M	74.7	13.0	6.2	20.0	50.0	50.0	80.8	19.2	100.0	48.6
Mean		52.6	17.7	51.4	12.4	31.5	68.5	52.1	47.9	98.2	82.4
SD		18.5	3.4	48.4	3.6	17.7	17.7	21.5	21.5	4.2	18.1

[a] This patient had aphasia due to traumatic brain injury. L1: Mandarin, L2: English, Edu: education, MPO: months post-onset, AoA: age of acquisition, LAR: language ability rating.

4.3.2 Standardized assessments and scoring

Participants were administered a battery of standardized language assessments and discourse tasks that were counterbalanced by language across testing sessions. Previous studies comparing in-person and teleassessment have reported no significant difference in performance between these two modalities (Dekhtyar et al., 2020; Theodoros et al., 2008). Hence, all the assessments in this study were conducted remotely via Zoom (https://zoom.us/) during the COVID-19 pandemic. Responses in each assessment were calculated based on guidelines within each test manual and aimed to comprehensively characterize language impairment in both languages. Measures of naming (i.e., Boston Naming Test, Northwestern Naming Battery, Northwestern Assessment of Verbs and Sentences) and discourse tasks (i.e., AphasiaBank) served as primary outcome measures for this study.

WAB-R and ABC

The WAB-R (Kertesz, 2007) and the ABC (Gao, 1993, 1996) were administered to measure the overall aphasia severity in English and Mandarin, respectively, as characterized by the Aphasia Quotient (AQ). The ABC is a Chinese-adapted version of the WAB-R. Previous studies have indicated its high reliability and validity based on assessment outcomes from 199 post-stroke patients with aphasia and 165 post-stroke patients without aphasia (Gao, 1993, 1996).

Boston Naming Tests

Single-word lexical retrieval in English was evaluated with the Boston Naming Test Long Form (BNT; Kaplan et al., 2001), which contains pictures of 60 common objects. A 30-item version for the Chinese BNT (Chen et al., 2014; Cheung et al., 2004) was administered to assess the noun-retrieval ability in Mandarin Chinese. This 30-item BNT has been culturally adapted and validated in Chinese speakers. A cut-off score of 24 in spontaneous naming generated a sensitivity of 73.1% and specificity of 75.3% in differentiating normal from participants with brain injury (Cheung et al., 2004), suggesting that the 30-item BNT is applicable to the Chinese-speaking population.

Northwestern Naming Battery & Northwestern Assessment of Verbs and Sentences

Confrontation naming of nouns and verbs was additionally administered using the Northwestern Naming Battery (NNB; Thompson et al., 2012) and the Verb Naming Test (VNT) from the Northwestern Assessment of Verbs and Sentences (NAVS, Thompson, 2012). The same subtests were administered using the Chinese NNB (Liao & Thompson, 2017) and NAVS (Wang & Thompson, 2016), which have been adapted and validated in Chinese-speaking individuals with aphasia.

Pyramids and Palm Trees Test

A three-picture version of the Pyramids and Palm Trees Test (PPT; Howard & Patterson, 1992) was administered to evaluate semantic processing in Mandarin-English BWA. This test was administered in the dominant or preferred language given that bilinguals have a shared semantic system across languages (Kroll & Stewart, 1994).

Cognitive Linguistic Quick Test

Executive functions were assessed using the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). This domain included three non-linguistic tasks (i.e., symbol trails, mazes, design generation) and one linguistic task (i.e., generative naming). In that previous studies suggest different mechanisms in processing language control and general cognitive control in BWA (Gray & Kiran, 2016), all of the non-linguistic tasks were assessed in the dominant or preferred language, and the linguistic tasks were assessed in both languages.

Discourse

Connected speech samples were collected in Mandarin and English in separate sessions using sequential-picture, single-picture, and storytelling tasks from the AphasiaBank (*https://aphasia.talkbank.org/*), which have been commonly implemented for assessing spontaneous speech for both clinical and research purposes (Chen et al., 2018; MacWhinney et al., 2011). Performance may highly vary across these tasks as they elicit distinctive linguistic and cognitive demands (Brady et al., 2005; Nicholas & Brookshire, 1993). The sequential pictures included a six-frame strip ("*Umbrella"*) that depicts the story of a young boy who refuses to take an umbrella from his mother when he leaves for school; on his way to school it starts raining so he returns home to take the umbrella. The single picture was *"Cat Rescue"* (Nicholas & Brookshire, 1993). In this picture, a girl's cat is on a tree and her dad has tried to rescue the cat but is stuck on the tree; so, the fire department comes to rescue the cat and the girl's father. The single- and sequential-picture stimuli were included in Appendix Figure 4.1 and can be found at: *www.talkbank.org/AphasiaBank/protocol/pictures.html*. Storytelling was assessed using *"The Tortoise and the Hare"* which is about a hare who falls asleep while running a race with a tortoise, then the tortoise wins the race. The rationale for choosing this story was because it is more culturally relevant to the Chinese population as compared to other stories such as *"Cinderella"* (Kong, 2017). Responses in these discourse tasks were transcribed by the first author using Computerized Language ANalysis (CLAN) program (MacWhinney, 2000).

Naming stimuli and psycholinguistic variables

Noun stimuli were composed of the same items in both Mandarin and English BNTs (n = 30 per language) and items that contributed to the noun-verb ratio on the NNB (n = 16 per language). Likewise, verb stimuli were composed of non-redundant items from the NNB and NAVS (n = 21 for Mandarin, n = 31 for English). See Appendix Table 4.1 for the stimuli.

Furthermore, psycholinguistic measures of nouns and verbs were obtained to examine their potential influence on naming performance. Specifically, frequency-per-million was extracted from the Subtlex-US (Brysbaert & New, 2009) for English and from the Subtlex-CH (Cai & Brysbaert, 2010) for Mandarin. Additionally, imageability and familiarity ratings were obtained from the Glasgow Norms (Scott et al., 2019) and the MRC Psycholinguistic Database (Coltheart, 1981), which both are based on 7-point scales (lower means less familiar or imageable). Since values of most stimuli are unavailable in the existing Chinese databases (Liu et al., 2007; Wang & Chen, 2020; Xu et al., 2021), imageability and familiarity ratings in English were used as approximate measures for all the Mandarin items. Previous studies have reported high correlations of imageability ratings across languages, suggesting that lexical-semantic ratings may be used cross-linguistically (Blomberg & Öberg, 2015; Rofes et al., 2018). Independent *t*-tests showed a significant difference between verbs and nouns for all variables in both Mandarin and English (Table 4.2).

Table 4.2. Psycholinguistic values of noun and verb stimuli by language.

	Log frequency		Familiarity		Imageability	
[a]L1						
	Noun	Verb	Noun	Verb	Noun	Verb
Mean	0.67	1.59	5.42	6.05	6.52	5.19
SD	0.80	0.70	0.91	0.37	0.43	0.87
t-value	-15.66**		-12.33**		20.28**	
L2						
	Noun	Verb	Noun	Verb	Noun	Verb
Mean	0.57	1.59	5.44	5.88	6.49	5.14
SD	0.72	0.69	0.91	0.57	0.43	0.84
t-value	-20.73**		-7.97**		25.37**	

Note: L1: Mandarin, L2: English; [a]Familiarity and imageability ratings in L2 were used as approximate measures for L1. **: *p*-value < 0.01.

4.3.3 Data analysis

Data analysis was conducted in R Studio (Version 4.1.0). To address the first research question, a linear mixed-effects model were fitted to the data using the *lmerTest* package (Kuznetsova et al., 2017) to examine the effect of word class on item-level response accuracy (0 = inaccurate, 1 = accurate). The fixed factors included word class (i.e., nouns, verbs), language (i.e., Mandarin, English), and the class*language interaction term. Random intercepts for subject and item were included to account for additional variance. Additionally, WAB-AQ and log frequency were included as the covariates. Two additional models were performed to control for imageability and familiarity ratings (Appendix Table 4.2). However, results were interpreted with caution since ratings in English were used as approximate measures for Mandarin. To estimate the main effects, sum-to-zero contrasts were coded for the categorical fixed factors (i.e., word class, language). Statistical significance was set at $p < 0.05$.

For the second research question, connected speech in both languages was analyzed using the Computerized Quantitative Production Analysis (C-QPA) command (Berndt et al., 2000; Saffran et al., 1989). The following measures for nouns and verbs have been previously reported in bilingual aphasia studies (Dai et al., 2012) and were used as primary outcome measures for the current analysis: (1) number of total nouns, (2) number of total verbs, (3) proportion of nouns (equation 4-1), and (4) proportion of verbs (equation 4-2). A linear regression model was conducted to examine the effect of word class on the proportion of lexical production in discourse. The fixed factors were word class (i.e., nouns, verbs), language (i.e., Mandarin, English), discourse task (i.e., *Umbrella, Cat Rescue, The Tortoise and the Hare*), and a three-way interaction between these factors. WAB-AQ was included as the covariate to account for the overall aphasia severity.

$$\frac{\#\ of\ nouns}{\#\ of\ nouns + \#\ of\ verbs} \qquad \text{Equation (4-1)}$$

$$\frac{\#\ of\ verbs}{\#\ of\ nouns + \#\ of\ verbs} \qquad \text{Equation (4-2)}$$

To answer the last research question, linear regression models were performed to examine the relationship between single-word naming and lexical retrieval in discourse. To promote a comparable measure to discourse production, a proportion of accurate object vs. action naming was calculated using equation (4-3) to capture the pattern of verb and noun impairment in single-word naming. Hence, a higher proportion of accurate nouns means a lower proportion of accurate verbs. In the model, the proportion of noun vs. verb production across all discourse tasks was the dependent variable (equation 4-1). The fixed factors included the proportion of accurate object vs. action naming, language (i.e., Mandarin, English), and the naming*language interaction. WAB-AQ was entered as the covariate.

$$\frac{\#\ of\ accurate\ nouns}{\#\ of\ accurate\ nouns + \#\ of\ accurate\ verbs} \qquad \textit{Equation (4-3)}$$

4.3.4 Reliability measure

Twenty percent of the discourse production was randomly selected and transcribed by a trained student. Inter-rater reliability was then calculated for the C-QPA measures (i.e., total number of narrative words, total number of nouns, total number of verbs, total number of utterances) using *Pearson's* correlations.

4.4 Results

Individual naming ability on each task is shown in Table 4.3. The mixed model results (Table 4.4) showed that lexical frequency was a significant predictor of the overall naming performance (i.e., higher naming accuracy for items with higher frequency; $p < 0.01$). There was also a significant main effect of word class ($\beta = 0.515$, SE = 0.162, $p < 0.01$), suggesting that naming accuracy was higher for nouns than verbs across languages. Further, a significant main effect of language above and beyond lexical frequency ($\beta = 0.289$, SE = 0.105, $p < 0.01$) indicated a lower naming accuracy in L2 (English) than in L1 (Mandarin). The results did not show a significant class*language interaction, that is, the effect of word class on naming was similar in both languages. Further, a significant main effect of AQ (*p*-value < 0.01) suggested a higher naming accuracy in individuals with higher AQ, i.e., lower aphasia severity.

Table 4.3. Standardized language measures and naming performance.

ID	WAB -AQ	ABC-AQ	EN BNT[a] %	CH BNT %	CLQT EF-NV	PPT %	EN NNB obj %	EN NNB act %	EN VNT %	CH NNB obj %	CH NNB act %	CH VNT %
P1	47.6	34.1	18.3	3.3	23.0	76.6	62.5	6.3	13.6	12.5	0.0	0.0
P2	92.3	86.9	80.0	73.3	17.0	96.9	100.0	87.5	86.4	100.0	87.5	80.0
P3	78.7	86.5	38.3	86.7	31.0	95.3	93.8	62.5	72.7	100.0	81.3	80.0
P4	68.6	51.2	26.7	16.7	28.0	93.8	81.3	25.0	45.5	25.0	6.3	5.0
P5	82.9	77.7	46.7	53.3	7.0	84.4	75.0	81.3	45.5	87.5	68.8	65.0
P6	82.8	87.6	31.7	73.3	25.0	98.4	75.0	68.8	72.7	100.0	87.5	95.0
P7	39.2	51.9	3.3	13.3	18.0	60.9	6.3	6.3	0.0	6.3	25.0	15.0
P8	13.3	50.0	0.0	3.3	16.0	75.0	0.0	0.0	0.0	12.5	25.0	15.0
P9	69.0	78.4	23.3	63.3	25.0	96.9	75.0	50.0	40.9	75.0	81.3	65.0
P10	93.8	88.3	53.3	53.3	29.0	98.4	93.8	93.8	81.8	93.8	93.8	90.0
P11	77.7	78.4	30.0	26.7	27.0	98.4	62.5	37.5	45.5	50.0	43.8	55.0
P12	82.9	90.9	33.3	93.3	23.0	95.3	87.5	43.8	50.0	93.8	62.5	60.0
Mean	69.1	71.8	32.1	46.7	22.4	89.2	67.7	46.9	46.2	63.0	55.2	52.1
SD	24.0	19.5	21.7	32.7	6.8	12.3	32.4	32.8	29.6	38.9	33.8	34.3

CH: Chinese; EN: English; WAB-AQ: Western Aphasia Battery Aphasia Quotient (total = 100); ABC-AQ: Aphasia Battery in Chinese Aphasia Quotient (total = 100); EN BNT = English Boston Naming Test (total = 60), [a]thirty of all the 60 items were included in the data analysis; CH BNT = Chinese Boston Naming Test (total = 30); CLQT EF-NV: Cognitive Linguistic Quick Test Executive Function Non-verbal (total = 31); PPT: Pyramids and Palm Trees (total = 64); NNB obj: Northwestern Naming Battery Object Naming (total = 16 in CH and EN); NNB act: Northwestern Naming Battery Action Naming (total = 16 in CH and EN); VNT: Verb Naming Test (total = 22 in EN; total = 20 in CH).

Table 4.4. Regression results from noun and verb naming.

	Estimate	**SE**	**Z-value**	***p-value***
Model 1: Accuracy ~ word class * lang + AQ + *log freq* + (1|item) + (1|subj)				
class (noun)	0.515	0.162	3.172	0.002**
lang (L1)	0.289	0.105	2.762	0.006**
class*lang	0.098	0.104	0.945	0.345
log freq	0.919	0.179	5.137	2.79e-07**
AQ	0.120	0.009	13.668	< 2e-16**

Note: lang: language, L1: Mandarin, log freq: log frequency, subj: subject, SE: standard error, AQ: Aphasia Quotient; *p*-value: ** = $p < 0.01$.

Group-level measures of Mandarin and English discourse tasks are illustrated in Table 4.5. Inter-rater reliability for these measures showed significant correlations in both L1 and L2 (Table 4.6). Figure 4.1 captures the average proportion of verb and noun production by the target language (i.e., L1, L2) in each discourse task (i.e., *Cat Rescue,* *Umbrella, The Tortoise and the Hare*). The regression results revealed a significant main effect of word class, i.e., verbs and nouns ($\beta = 0.067$, SE = 0.016, $p < 0.01$), suggesting a verb-noun dissociation across languages and tasks (i.e., higher proportion of nouns than verbs). There was also a significant class*task interaction (*Cat Rescue:* $\beta = 0.057$, SE = 0.022, $p < 0.05$) and a significant class*language interaction (L1: $\beta = -0.038$, SE = 0.016, $p < 0.05$). *Post-hoc* pairwise comparisons were performed using the *emmeans* package in R Studio (Tukey method). Results showed that there was a higher proportion of nouns than verbs in both L1 ($p < 0.05$) and L2 ($p < 0.01$) in *Cat Rescue*, and in L2 in *The Tortoise and the Hare* ($p < 0.05$). These findings suggested that the verb-noun dissociation emerged in L1 and L2 to varying degrees, depending on the type of task.

To further examine factors that might have affected the cross-language difference in the verb and noun dissociation (i.e., a significant class*language interaction as mentioned above), linear regression was carried out to assess the effect of aphasia severity (i.e., WAB-AQ) across all three discourse tasks. Results captured a significant AQ*class interaction ($\beta = -0.005$, SE = 0.001, $p < 0.01$) and a significant AQ*class*language three-way interaction ($\beta = 0.003$, SE = 0.001, $p < 0.01$), suggesting that the cross-linguistic difference of the verb-noun dissociation in discourse was diminished in individuals with higher AQ, i.e., lower aphasia severity.

Table 4.5. Group-level measures of discourse production in L1 and L2.

	L1				L2			
	Mean	**SD**	**Min.**	**Max.**	**Mean**	**SD**	**Min.**	**Max.**
# Narrative Words								
Cat	38.83	28.49	0.00	82.00	40.00	25.82	0.00	86.00
Tortoise	50.33	38.37	2.00	125.00	50.33	42.33	1.00	136.00
Umbrella	42.17	27.36	2.00	77.00	42.08	27.04	4.00	99.00
# Nouns								
Cat	9.50	6.54	0.00	21.00	10.42	6.36	0.00	21.00
Tortoise	10.67	6.75	0.00	21.00	12.17	9.84	0.00	33.00
Umbrella	9.75	6.28	0.00	21.00	9.17	6.07	0.00	21.00
Noun Proportion %								
Cat	61.07	16.08	50.00	100.00	63.77	16.48	47.06	100.00
Tortoise	49.43	16.82	0.00	66.67	61.38	15.78	44.00	100.00
Umbrella	48.29	22.04	0.00	87.50	56.13	18.13	35.00	100.00
# Verbs								
Cat	6.92	5.79	0.00	17.00	7.50	6.05	0.00	20.00
Tortoise	10.00	7.26	1.00	22.00	9.25	8.30	0.00	25.00
Umbrella	9.17	6.19	1.00	21.00	8.42	6.73	0.00	23.00
Verb Proportion %								
Cat	38.93	16.09	0.00	50.00	36.23	16.48	0.00	52.90
Tortoise	50.58	16.81	33.30	100.00	38.63	15.78	0.00	56.00
Umbrella	51.70	22.04	12.50	100.00	43.88	18.14	0.00	65.00
# Utterances								
Cat	5.75	3.22	0.00	10.00	6.42	3.26	0.00	11.00
Tortoise	7.83	4.20	2.00	16.00	9.00	5.05	2.00	20.00
Umbrella	7.50	2.50	3.00	11.00	6.83	2.52	3.00	12.00

L1: Mandarin; L2: English; SD: standard deviation; Min.: minimum; Max.: maximum; Cat = Cat Rescue; Tortoise: The Tortoise and the Hare; Noun Proportion (%): # Nouns / (# Nouns + # Verbs); Verb Proportion (%): # Verbs / (# Nouns + # Verbs).

Table 4.6. Inter-rater reliability measures (Pearson's r) of discourse production.

	Total # of Narrative Words	Total # of Utterances	Total # of Nouns	Total # of Verbs
L1	0.95**	0.91**	0.95**	0.99**
L2	0.95**	0.90**	0.89**	0.96**

L1: Mandarin, L2: English; **: *p*-value < 0.01.

Figure 4.1. The proportion of nouns and verbs in L1 (Mandarin) and L2 (English) discourse production. A boxplot showing the average proportion of verb and noun production by the target language in each discourse task (i.e., Umbrella, Cat Rescue, The Tortoise and the Hare); Y-axis: Proportion of lexical production (1.00 = 100%); Noun Proportion: # Nouns / (# Nouns + # Verbs); Verb Proportion: # Verbs / (# Nouns + # Verbs). Significant difference between nouns and verbs was found in L1 ($p < 0.05$) and L2 ($p < 0.01$) in Cat Rescue, and in L2 in The Tortoise and the Hare ($p < 0.05$).

The relationship between naming and lexical retrieval in discourse is illustrated in Figure 4.2. The regression results revealed that lexical retrieval in discourse was significantly predicted by single-word naming after accounting for aphasia severity (β = 0.90, SE = 0.18, $p < 0.01$), suggesting that a higher proportion of accurate nouns (i.e., a lower proportion of accurate verbs) in naming was associated with a higher proportion of noun production (i.e., a lower proportion of verb production) in discourse. In addition, there was not a significant interaction between the target language (i.e., L1, L2) and naming performance ($p > 0.05$). These findings altogether indicated a similar pattern of verb and noun dissociation across single-word naming and discourse production irrespective of the target language. In addition, naming performance could be a significant indicator of lexical retrieval in discourse in Mandarin-English BWA.

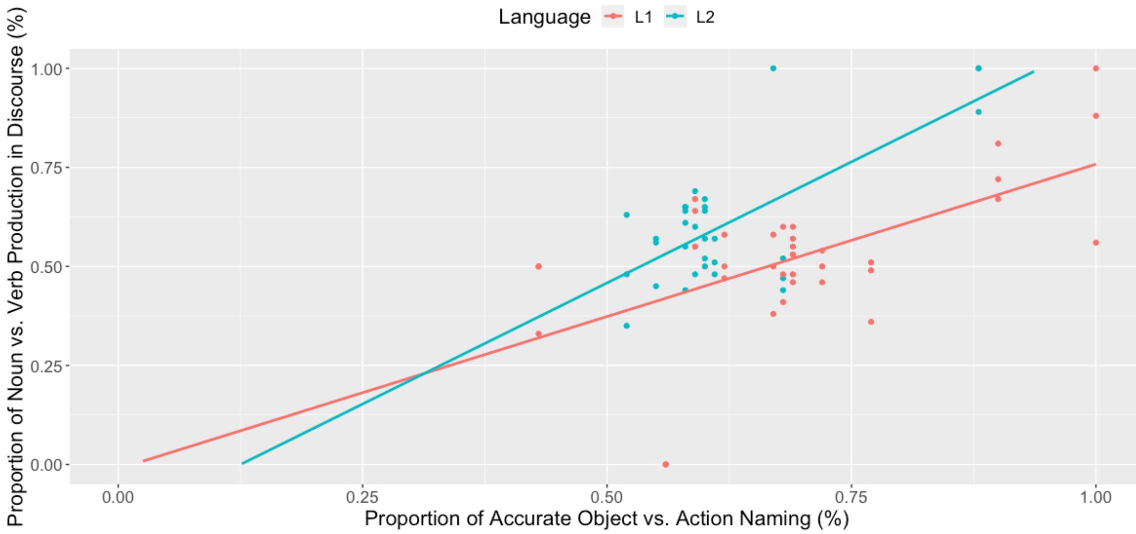


Figure 4.2. Relationship between naming and lexical retrieval in discourse in L1 (Mandarin) and L2 (English). X-axis: the proportion of accurate object vs. action naming (equation 4-3; 1.00 = 100%); 100% of accurate object naming means 0% of accurate action naming. Y-axis: the proportion of noun vs. verb production across all three discourse tasks (equation 4-1; 1.00 = 100%); 100% of noun production means 0% of verb production. A positive relationship was identified between naming and discourse ($p < 0.01$). No significant class*language interaction ($p > 0.05$).

4.5 Discussion

The current study aimed to investigate patterns of verb and noun impairment in Mandarin-English BWA. Specifically, we examined to what extent: (1) a verb and noun dissociation emerged at the *single-word* level, (2) a verb and noun dissociation emerged at the *discourse* level, and (3) a similar pattern of verb and noun dissociation emerged across single-word naming and discourse production. The study to our knowledge is the first one that systematically examined word-retrieval abilities for verbs and nouns in a group of Mandarin-English BWA. Results partially support previous studies that investigated verb and noun impairment in BWA. In general, Mandarin-English BWA performed better in their L1 (Mandarin) than in L2 (English) in single-word naming. Across L1 and L2, naming accuracy for nouns was higher than for verbs. This pattern of verb-noun dissociation was not language-dependent, suggesting that grammatical category information is shared between languages.

In discourse production, Mandarin-English BWA demonstrated a higher proportion of noun production than verb production across languages and tasks, corroborating previous evidence of a verb-noun dissociation in lexical retrieval. In addition, there was a higher proportion of nouns than verbs in both L1 and L2 in single-picture description and in L2 storytelling. These results suggest that depending on the discourse task, the verb-noun dissociation emerged in L2 to a greater extent than in L1. This cross-linguistic difference of the verb-noun dissociation was diminished in individuals with higher AQ, i.e., lower aphasia severity. Finally, our linear regression results showed that irrespective of the language, a higher proportion of accurate nouns (i.e., a lower proportion of accurate verbs) in naming was associated with a higher proportion of noun production (i.e., a lower proportion of verb production) in discourse. These results altogether pointed to a similar pattern of verb and noun dissociation across different linguistic contexts. However, depending on the cognitive-linguistic demands of the context/task, the verb-noun dissociation may emerge in L1 and L2 to varying degrees in individuals with different levels of aphasia severity. Findings in our study help uncover the patterns of lexical impairment in Mandarin-English BWA and highlight the value of using discourse analysis as tools to study bilingual language recovery. In the discussion that follows, we elaborate on these findings.

4.5.1 Verb-noun dissociation in naming

Consistent with our predictions, the findings revealed a pattern of verb-noun dissociation in single-word naming (i.e., lower naming accuracy for verbs than nouns) after controlling for lexical frequency. While the patterns of verb-noun impairment varied across previous studies (Kremin & De Agostini, 1995; Sasanuma & Park, 1995; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Faroqi-Shah & Waked, 2010; Kambanaros, 2010; Dai et al., 2012), the current finding of a verb and noun dissociation is in-line with more recent studies that have reported a similar pattern in BWA (Kambanaros, 2010; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007). Even in healthy bilinguals, verbs are more difficult to access than nouns due to a weaker cross-linguistic connection at the conceptual level, as posited by the *Distributed Feature Model* (Van Hell & De Groot, 1998). This model assumes that bilinguals would perform worse on tasks involving verb access as compared to noun access. Hence, the dissociation between action and object naming in this study suggests that these weaker connections at the semantic representation level affect verbs more following brain damage in BWA.

Although the current study did not aim to investigate the linguistic mechanisms underlying the verb-noun dissociation, we noticed that the effect of word class disappeared after *imageability* was controlled for (Appendix Table 4.2). Previous research has posited that imageability has strong effects on object and action naming because concrete words benefit from conceptual specificity and redundancy between concepts, whereas the conceptual connections between abstract words are relatively loose (Kiran & Tuchtenhagen, 2005). Given that verbs were significantly less imageable than nouns in this study (Table 4.2), our finding supports this hypothesis and suggests that the dissociation between verbs and nouns may arise at the semantic/conceptual level of lexical processing (Bird, Howard, et al., 2001; Poncelet et al., 2007; Shapiro & Caramazza, 2003). However, while this finding resonates with previous studies examining the effect of imageability in verb and noun processing (Kambanaros, 2010b; Kiran & Tuchtenhagen, 2005; Luzzatti et al., 2002), we recognize that it needs to be interpreted with caution given that imageability ratings in English were used as approximate measures for Mandarin in our study.

Mandarin-English BWA also performed better in their L1 than in L2, as evidenced by higher naming accuracy across verbs and nouns in L1 (Mandarin). This L1 advantage corresponded to the fact that most of the participants reported higher ratings of their pre-stroke language ability in L1 relative to L2 (LAR, Table 4.1). This result supports the growing body of evidence suggesting that pre-stroke language proficiency may be a strong predictor of bilingual aphasia recovery (Kuzmina et al., 2019; Lorenzen & Murray, 2008; Peñaloza et al., 2019).

Although the overall naming performance across verbs and nouns was better in L1 than in L2, the verb-noun dissociation discussed above was similar in both languages. The majority of previous research also identified a similar pattern of verb-noun dissociation in L1 and L2 (Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Miozzo et al., 2010). Our study successfully replicated this finding when extended to typologically dissimilar languages, i.e., Mandarin-English. According to a previous neurophysiological account, verbs and nouns of both languages are processed in a similar manner by the same neural substrates (Miozzo et al., 2010). Our finding supports this account and suggests that the organization of verbs and nouns is likely shared across languages. This account holds true even in languages that vary in morphosyntactic structure. In English, verbs are marked by grammatical morphology, such as number, person, and tense markers, whereas verbs in Mandarin Chinese do not carry these linguistic markers (Gentner, 2006). Given the variability in morphosyntax between English and Mandarin, the source of the verb-noun dissociation may not stem from the cross-linguistic differences, but instead from the semantic representation level in bilingual lexical processing (Kroll & Stewart, 1994).

4.5.2 Verb-noun dissociation in discourse and its relationship with naming

In discourse production, Mandarin-English BWA exhibited a higher proportion of noun production than verb production across languages and tasks, supporting a verb-noun dissociation. More interestingly, the verb-noun dissociation emerged in L1 (Mandarin) and L2 (English) to varying degrees, depending on the task. Specifically, the proportion of nouns was higher than the proportion of verbs in both L1 and L2 in single-picture description, whereas the proportion of nouns was higher than the proportion of verbs in L2 in storytelling. Taken together, these findings can be explained by a combination of task- and individual-related factors, including: (1) cognitive-linguistic demands of language contexts, (2) premorbid language proficiency in L1 and L2, and (3) individual aphasia severity. While the verb-noun dissociation in discourse emerged in languages and tasks to different degrees, our regression results revealed an overall positive relationship between naming and lexical retrieval in discourse irrespective of the target language. We unpack each of these points in the following paragraphs.

In comparison with naming, discourse production involves more activation and interaction of both cognitive and linguistic subsystems, which are commonly affected in individuals with aphasia (Linnik et al., 2016). The effect of linguistic context, i.e., single-word naming vs. connected speech, on lexical retrieval has been previously investigated in aphasia studies, but mainly focused on monolinguals with aphasia (Law et al., 2015; Mayer & Murray, 2003; Pashek & Tompkins, 2002; Wilshire & McCarthy, 2002). Some of these studies suggest that linguistic context highly influences lexical retrieval due to different processing demands. In discourse production, there tend to be more semantic alternatives to the target competing for lexical selection, whereas lexical selection in naming is relatively more context-constrained as the target word is the preferred choice for production (Law et al., 2015; Wilshire & McCarthy, 2002). Hence, while the verb-noun dissociation was found in both naming and discourse, the processing demand might be higher for discourse production.

Different types of discourse tasks also impose distinctive cognitive-linguistic demands, which may differentially impact lexical retrieval in individuals with aphasia (Brady et al., 2005; Nicholas & Brookshire, 1993). In our study, a verb-noun dissociation was found in both single-picture description and storytelling, but to a larger extent in the former. In conversation, speakers usually establish main ideas via communicating the relations and causal links among units of information (van Dijk & Kintsch, 1983). This claim is supported by previous research in both healthy adults and individuals with aphasia (Capilouto et al., 2005; Fergadiotis & Wright, 2014). In general, these studies found less production of main events from the single pictures versus sequential pictures and storytelling, suggesting that single pictures convey less temporal and causal information about a story. As a result, participants may simply list the objects without considering the events or underlying relationships, leading to less production of verbs than nouns (Fergadiotis & Wright, 2014). Our results corroborate this account and further suggest that irrespective of the language, verb retrieval in BWA is particularly sensitive to discourse tasks that include fewer causal links among information. However, these presumptions should be investigated in future research targeting different bilingual populations with aphasia.

Relative to L1 (Mandarin), Mandarin-English BWA demonstrated a verb-noun dissociation to a greater extent in their L2. One explanation of this finding is the variability in language history. Among many other individual factors that impact bilingual language impairment, a lower L2 proficiency and a late AoA have been consistently associated with poorer language performance across studies (Kuzmina et al., 2019; Peñaloza & Kiran, 2019). Given that our participants had a late L2 AoA (mean = 12.4 years) and a lower premorbid LAR for L2 (mean = 82.4%) as compared to L1 (mean = 98.2%), verb production in discourse might be more impaired in the less proficient language, i.e., L2. This finding can also be explained by the *Revised Hierarchical Model* (Kroll & Stewart, 1994), which assumes a stronger link between the conceptual system and lexical system of L1 than between the conceptual system and lexical system of L2. Hence, accessing the semantics of verbs in the less proficient language may be affected to a larger extent than in the more proficient language. This presumption can be tested in future research via an error analysis to examine whether there are more semantic errors for verbs than noun in L2.

We further found that the cross-linguistic difference of the verb-noun dissociation was diminished in individuals with higher WAB-AQ (i.e., lower aphasia severity). The effect of aphasia severity/type on the verb and noun impairment in connected speech is still unclear across previous bilingual aphasia studies (Dai et al., 2012; Faroqi-Shah & Waked, 2010; Kambanaros, 2007). Two of these studies did not identify a verb-noun dissociation in connected speech in either language of bilinguals with mild aphasia (Dai et al., 2012; Kambanaros, 2007). However, they did not include individuals with more severe aphasia for comparison. One account claimed that individuals with mild aphasia tend to have less difficulty with verb retrieval relative to those with more severe aphasia, leading to a smaller or even no grammatical category dissociation in connected speech (Berndt et al., 1997). However, evidence supporting this account has mainly come from monolinguals with aphasia (Law et al., 2015; Mayer & Murray, 2003; Pashek & Tompkins, 2002; Wilshire & McCarthy, 2002). Our results partially support this account and suggest that relative to bilinguals with severe aphasia, those with mild aphasia demonstrated a smaller verb-noun dissociation, particularly in their L2.

Notwithstanding the above factors that may affect verb and noun impairment in discourse production, our results pointed to a similar pattern of verb-noun dissociation in single-word naming and discourse production in Mandarin-English BWA. These findings suggest a consistent verb-noun dissociation across tasks regardless of the variability in cognitive-linguistic demands. More interestingly, the pattern of lexical impairment was similar across Mandarin and English irrespective of the language context. This finding is in contrast with previous research examining verb and noun processing across typologically dissimilar languages (Sung et al., 2016). Although evidence came from monolinguals with aphasia, this previous study found that Korean-speaking individuals with aphasia produced more verbs than nouns in connected speech, whereas English-speaking individuals with aphasia produced more nouns than verbs. The authors argued that this cross-linguistic disparity was attributed to the different syntactic structures between Korean (subject-object-verb/SOV) and English (subject-verb-object/SVO). However, our findings do not support this claim because Mandarin and English follow the same SVO word order (Tardif, 1994). Hence, our study indicates that the verb-noun dissociation in Mandarin-English BWA may not be driven by language-specific features, but instead by the lexical-semantic properties between grammatical categories.

In the literature of BWA, most studies examining verb and noun retrieval in both naming and connected speech have either revealed the opposite (i.e., superior verb impairment in naming than discourse) or no direct relationship (Dai et al., 2012; Kambanaros, 2007). Several key methodological differences might have caused the disparity in findings. For example, the stimuli and patient samples varied across studies, which might have affected the underlying relationship between naming and discourse. Also, the previous studies either did not carry out a direct comparison between naming and discourse (Dai et al., 2012) or only examined the relationship using correlational analysis without accounting for individual factors, such as aphasia severity (Kambanaros, 2007). As highlighted in previous reviews (Armstrong, 2000; Linnik et al., 2016), future research can benefit from comparative evaluation of existing methods to better reproduce results of earlier studies. Findings from our study indicate that quantitative measure of verbs and nouns in discourse production can be a reliable tool to capture lexical-retrieval abilities in

Mandarin-English BWA. These measures can help detect lexical impairment of different grammatical categories in individuals with variability in aphasia severity and language proficiency. This is particularly relevant to improve diagnosis and intervention for bilinguals with lexical impairment.

4.6 Limitations and future implications

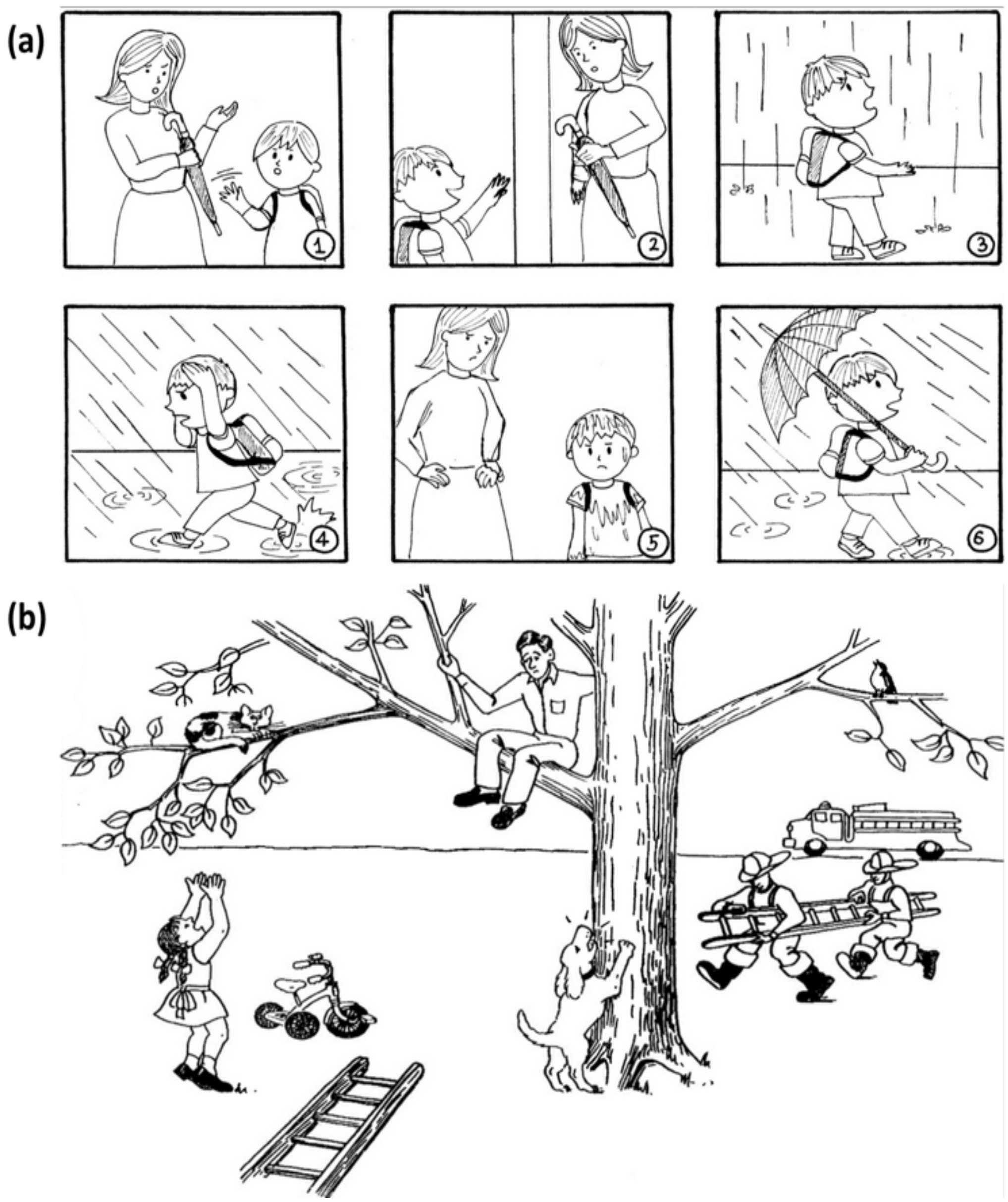
Despite the findings discussed above in support of a verb-noun dissociation in both naming and discourse production in Mandarin-English BWA, there are several limitations in this study. First, we used imageability and familiarity ratings in English as approximate measures for Mandarin because values would be missing for most items if they were extracted from the existing Chinese databases (Liu et al., 2007; Wang & Chen, 2020; Xu et al., 2021). Although previous studies have argued that same lexical-semantic values could be used cross-linguistically (Blomberg & Öberg, 2015; Rofes et al., 2018), results would be more informative if values for each language were available. Hence, for future research there is in an urgent need to develop larger databases for use in bilingual language research. Second, future research could examine error patterns in both naming and discourse production to better understand the linguistic mechanisms underlying the verb-noun dissociation across different contexts. Finally, the current study found that the verb-noun dissociation in discourse differed by task. Future research in BWA could examine the effect of cognitive-linguistic demands on lexical retrieval in different types of tasks and thereby clarify the links between cognitive functions and bilingual language recovery.

4.7 Conclusion

This study aimed to investigate patterns of verb and noun impairment in single-word naming and discourse production in Mandarin-English BWA. Our results showed a verb and noun dissociation in single-word naming, which was similar in L1 (Mandarin) and L2 (English). Another pattern of verb and noun dissociation was captured in discourse production. However, depending on the task, the verb-noun dissociation emerged in L2 to a greater extent than in L1. This cross-linguistic difference of the verb-noun dissociation in discourse production was diminished in individuals with lower aphasia severity. Although the verb-noun dissociation in discourse production emerged in L1 and L2 to varying degrees, our results pointed to an overall direct relationship between naming and lexical retrieval in discourse irrespective of the language. Our results add to the growing body of literature concerning a verb and noun dissociation in bilingual aphasia when extended to typologically dissimilar languages, i.e., Mandarin-English. Results may facilitate greater understanding of bilingual lexical processing and highlight the value of using discourse production in addition to single-word naming as tools for clinical diagnosis and treatment for BWA.

4.8 Appendix

Appendix Figure 4.1. Picture stimuli for the discourse tasks. (a) *Umbrella* (sequential-picture), (b) *Cat Rescue* (single-picture).



Appendix Table 4.1. Verb and noun naming stimuli in English and Mandarin with psycholinguistic values.

Item	Language	Source	Category	Freq	Fam	Image
abacus	C	BNT	Noun	0.95		
accordion	C	BNT	Noun	0.83	3.794	6.273
broom	C	BNT	Noun	1.25	5.515	6.455
cactus	C	BNT	Noun	2.68	4.324	6.771
camel	C	BNT	Noun	6.86	4.793	6.633
compass	C	BNT	Noun	0.15	4.968	6.324
dart	C	BNT	Noun	4.11	4.96	5.97
escalator	C	BNT	Noun	0.72		
flower	C	BNT	Noun	266.7	6.6	6.788
funnel	C	BNT	Noun	0.86		
hanger	C	BNT	Noun	22.76		
harmonica	C	BNT	Noun	1.31	4.794	6.647
harp	C	BNT	Noun	1.34	4.603	6.613
igloo	C	BNT	Noun		3.844	6.548
mushroom	C	BNT	Noun	6.68	6.063	6.849
pencil	C	BNT	Noun	7.27	6.231	6.92
protractor	C	BNT	Noun	0.06		
pyramid	C	BNT	Noun	3.96	5.875	6.879
racquet	C	BNT	Noun	0.98	4.8	5.22
rhinoceros	C	BNT	Noun	2.71	5.061	6.818
saw	C	BNT	Noun	1.37	5.52	5.31
scissors	C	BNT	Noun	11.6	5.909	6.543
seahorse	C	BNT	Noun	0.8	5.265	6.686
snail	C	BNT	Noun	1.58	5.125	6.815
stethoscope	C	BNT	Noun	0.45	4.4	6.321
tongs	C	BNT	Noun	2.33		
tree	C	BNT	Noun	64.09	6.5	6.69
trellis	C	BNT	Noun	0.09	2.546	5.087
tripod	C	BNT	Noun	0.72	4.303	6.177
wheelchair	C	BNT	Noun	11.3		
bear	C	NNB	Noun	43.82	5.61	6.57
belt	C	NNB	Noun	8.38	6.19	6.34
camel	C	NNB	Noun	6.86	4.79	6.63
dress	C	NNB	Noun	34.67	6.71	6.73

elephant	C	NNB	Noun	12.4	5.9	6.86
frog	C	NNB	Noun	10.11	5.43	6.89
glove	C	NNB	Noun	20.15	6.19	6.68
hat	C	NNB	Noun	46.29	6.25	6.79
pants	C	NNB	Noun	55.77	5.75	6.3
rabbit	C	NNB	Noun	23.76	6.29	6.79
shirt	C	NNB	Noun	25.28	6.44	6.69
shoe	C	NNB	Noun	69.52	6.49	6.79
snake	C	NNB	Noun	30.49	5.65	6.66
sock	C	NNB	Noun	15.65	6.16	6.65
squirrel	C	NNB	Noun	7.18	5.52	6.68
tiger	C	NNB	Noun	10.97	6.21	6.73
abacus	E	BNT	Noun	0.24		
accordion	E	BNT	Noun	1.31	3.794	6.273
broom	E	BNT	Noun	4.76	5.515	6.455
cactus	E	BNT	Noun	2.9	4.324	6.771
camel	E	BNT	Noun	5.02	4.793	6.633
compass	E	BNT	Noun	4.06	4.968	6.324
dart	E	BNT	Noun	1.92	4.96	5.97
escalator	E	BNT	Noun	1.29		
flower	E	BNT	Noun	22.76	6.6	6.788
funnel	E	BNT	Noun	1.1		
hanger	E	BNT	Noun	1.35		
harmonica	E	BNT	Noun	1.75	4.794	6.647
harp	E	BNT	Noun	2.63	4.603	6.613
igloo	E	BNT	Noun	0.29	3.844	6.548
mushroom	E	BNT	Noun	2.14	6.063	6.849
pencil	E	BNT	Noun	9.86	6.231	6.92
protractor	E	BNT	Noun	0.06		
pyramid	E	BNT	Noun	4	5.875	6.879
racquet	E	BNT	Noun	0.33	4.8	5.22
rhinoceros	E	BNT	Noun	0.75	5.061	6.818
saw	E	BNT	Noun	6.92	5.52	5.31
scissors	E	BNT	Noun	6.69	5.909	6.543
seahorse	E	BNT	Noun	0.14	5.265	6.686
snail	E	BNT	Noun	1.76	5.125	6.815
stethoscope	E	BNT	Noun	0.94	4.4	6.321
tongs	E	BNT	Noun	0.78		

tree	E	BNT	Noun	65	6.5	6.69
trellis	E	BNT	Noun	0.27	2.546	5.087
tripod	E	BNT	Noun	0.9	4.303	6.177
wheelchair	E	BNT	Noun	6.2		
apple	E	NNB	Noun	23.67	6.72	6.91
belt	E	NNB	Noun	24.35	6.19	6.34
broom	E	NNB	Noun	4.76	5.52	6.46
cat	E	NNB	Noun	66.33	6.38	6.77
corn	E	NNB	Noun	14.22	5.29	6.29
elephant	E	NNB	Noun	11.37	5.9	6.86
glove	E	NNB	Noun	10.1	6.19	6.68
hammer	E	NNB	Noun	12.47	5.47	6.63
mouse	E	NNB	Noun	19.12	6.06	6.69
onion	E	NNB	Noun	4.24	6.71	6.64
pepper	E	NNB	Noun	8.8	6.46	6.68
scissors	E	NNB	Noun	6.69	5.91	6.54
snake	E	NNB	Noun	22.35	5.65	6.66
sock	E	NNB	Noun	8.98	6.16	6.65
suit	E	NNB	Noun	68.61	5.7	6.24
tie	E	NNB	Noun	44.43	6.23	6.68
gift	C	VNT	Verb	2.86	6.3	5.58
give	C	VNT	Verb	3494.19	6.57	3.65
sell	C	VNT	Verb	222.82	6.15	4.26
squat	C	VNT	Verb	25.76	5.76	5.65
teach	C	VNT	Verb	152.83	6.14	3.55
arrest	C	NNB	Verb	62.72	5.58	5.4
award	C	NNB	Verb	20.45	5.91	5.65
cut	C	NNB	Verb	30.82	6.13	6.13
drunk	C	NNB	Verb	75.24	6.58	5.86
fall	C	NNB	Verb	41.2	5.79	5.03
feed	C	NNB	Verb	336.43		
inquire	C	NNB	Verb	18.63		
kick	C	NNB	Verb	67.55	6.29	5.83
kneel	C	NNB	Verb	9.78	5.71	5.74
praise	C	NNB	Verb	3.82	5.76	4.11
ride	C	NNB	Verb	42.42	5.61	5.42
shower	C	NNB	Verb	28.26		
sleep	C	NNB	Verb	119.21	6.84	5.94

spray	C	NNB	Verb	7.33	5.58	5.29
swim	C	NNB	Verb	26.59	6.41	6.41
visit	C	NNB	Verb	4.98	5.81	3.85
bark	E	NNB	Verb	5.49	5.47	5.09
climb	E	NNB	Verb	19.75	5.82	5.41
crawl	E	NNB	Verb	12.04	5.52	5.5
cry	E	NNB	Verb	65.65	6.44	5.88
jump	E	NNB	Verb	69.82	5.51	5.06
pour	E	NNB	Verb	15.12	5.45	4.95
pray	E	NNB	Verb	36.22	4.73	5.17
pull	E	NNB	Verb	146.45	5.97	4.42
read	E	NNB	Verb	241.22	6.57	5.88
spill	E	NNB	Verb	8.47		
stir	E	NNB	Verb	5.9	5.88	5.44
sweep	E	NNB	Verb	9.51	5.06	5.52
swim	E	NNB	Verb	31.8	6.41	6.41
throw	E	NNB	Verb	128.82	6	5.09
write	E	NNB	Verb	126.8	6.53	5
zip	E	NNB	Verb	7.63		
bite	E	VNT	Verb	40.78	5.93	5.53
cut	E	VNT	Verb	229.76	6.13	6.13
deliver	E	VNT	Verb	28.35	5.29	3.88
drive	E	VNT	Verb	153.14	6.1	5.25
give	E	VNT	Verb	1167.82	6.57	3.65
howl	E	VNT	Verb	2.06	4.47	5.36
laugh	E	VNT	Verb	62.86	6.65	5.62
pinch	E	VNT	Verb	6.12	5.75	5.56
put	E	VNT	Verb	828.45	5.39	2.63
send	E	VNT	Verb	179.78	6.47	3.61
shave	E	VNT	Verb	13.76	6.06	5.54
shove	E	VNT	Verb	13.22		
tickle	E	VNT	Verb	4.8	6.23	5.09
wash	E	VNT	Verb	40.73		
watch	E	VNT	Verb	330.02	6.42	6.19

Note: C: Mandarin Chinese, E: English. BNT: Boston Naming Test, NNB: Northwestern Naming Battery, VNT: Verb Naming Test. Freq: frequency (word/million), Fam: familiarity (7-pt scale, lower = less familiar), Image: imageability (7-pt scale, lower = less imageable). Familiarity and imageability ratings in English were used as approximate measures for Mandarin.

Appendix Table 4.2. Additional regression results of noun and verb naming.

	Estimate	**SE**	**Z-value**	***p-value***
Model 2: Accuracy ~ word class * lang + AQ + *fam* + (1|item) + (1|subj)				
class (noun)	0.562	0.152	3.685	2.28e-4**
lang (L1)	0.189	0.108	1.751	0.080
class*lang	0.186	0.107	1.739	0.082
fam	1.441	0.203	7.085	1.39e-12**
AQ	0.115	0.009	13.303	< 2e-16**
Model 3: Accuracy ~ word class * lang + AQ + *image* + (1|item) + (1|subj)				
class (noun)	-0.107	0.268	-0.399	0.690
lang (L1)	0.231	0.121	1.916	0.055
class*lang	0.172	0.120	1.437	0.151
image	0.563	0.284	1.980	0.048*
AQ	0.116	0.009	13.411	< 2e-16**

Note: additional regression results examining noun and verb naming in Mandarin-English BWA. Familiarity and imageability were significant predictors of the overall naming accuracy; A significant main effect of word class was found after controlling for familiarity but not after controlling for imageability; No significant language*class interaction; lang: language, L1: Mandarin, fam: familiarity, image: imageability, subj: subject, SE: standard error, AQ: Aphasia Quotient; *p*-value: ** = $p < 0.01$, * = $p < 0.05$.

5. TREATMENT-INDUCED RECOVERY PATTERNS BETWEEN TRAINING NOUNS AND VERBS IN MANDARIN-ENGLISH BILINGUALS WITH APHASIA: A CROSS-OVER EXPERIMENTAL DESIGN

5.1 Background

Bilingual aphasia refers to the loss of function in one or both languages (Paradis, 2001). Different patterns of language impairment may emerge due to complex interactions among factors, including bilingual language history and cross-linguistic differences (Fabbro, 2001; Kuzmina et al., 2019; Lorenzen & Murray, 2008; Paradis, 2001). In the U.S., Chinese is the third mostly spoken language, following English and Spanish (Zeigler & Camarota, 2019). The growing bilingual population coincides with an overall increase of older people at risk for neurogenic disorders, i.e., stroke and dementia (Hoeffel et al., 2012). However, evidence of language recovery in bilinguals with aphasia (BWA) is mainly derived from individuals speaking Indo-European languages (e.g., Spanish-English). Given the increase in Chinese-speaking individuals, there is an urgent need to establish the evidence base for this bilingual population with aphasia.

Language intervention is a critical component of recovery for communication deficits and quality of life changes in BWA. Most previous studies examining the effect of naming therapy in BWA have reported significant improvement in the trained items (Abutalebi et al., 2009; Faroqi-Shah et al., 2010; Gil & Goral, 2004; Kiran et al., 2013; Lerman et al., 2019; Li et al., 2020; Meinzer et al., 2007; Peñaloza et al., 2020). However, one conceptual challenge in bilingual aphasia rehabilitation is whether training one language can generalize to the untrained language (i.e., cross-language generalization). Evidence of cross-language generalization is inconsistent across previous studies as some have identified both treatment gains and cross-language generalization (Edmonds & Kiran, 2006; Goral et al., 2012; Kiran & Iakupova, 2011; Kiran & Roberts, 2010; Lerman et al., 2017; Li et al., 2020; Miertsch et al., 2009), whereas others have only observed direct treatment gains (Galvez & Hinckley, 2003).

Among various treatment approaches targeting lexical impairment in BWA, semantic-based treatment has shown positive treatment gains and generalizations (Croft et al., 2011; Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Iakupova, 2011; Kiran & Roberts, 2010). Theoretically, since bilingual lexicons share the same semantic system (Costa et al., 2006; Hermans et al., 1998), training lexical semantics should not only induce spreading activation from the semantic system to semantically-related items in the same language (i.e., within-language generalization), but also to items in the untreated language (i.e., cross-language generalization). Kiran and colleagues have previously modified Semantic Feature Analysis (SFA; Boyle & Coelho, 1995; Boyle, 2004; Coelho et al., 2000) and replicated this approach in bilinguals with a variety of language combinations (Edmonds & Kiran, 2006; Kiran et al., 2013; Kiran & Iakupova, 2011; Kiran & Roberts, 2010). In general, these studies showed a robust treatment gain and within-language generalization, with varying patterns of cross-language generalization across participants. These findings suggest that semantic-based treatment effectively improves lexical retrieval ability in BWA.

Most previous studies in bilingual aphasia rehabilitation have focused on nouns. Nevertheless, lexical retrieval of other word categories (i.e., verbs) may also be affected after brain damage (Bastiaanse & Jonkers, 1998; Marshall et al., 1998; Vigliocco et al., 2011). There has been evidence suggesting that patterns of lexical impairment differ by a specific grammatical category (i.e., nouns or verbs) in both monolinguals with aphasia (Berndt et al., 1997; Kim & Thompson, 2000; Miceli et al., 1984; Zingeser & Berndt, 1990) and BWA (Kremin & De Agostini, 1995; Sasanuma & Park, 1995; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Faroqi-Shah & Waked, 2010; Kambanaros, 2010; Dai et al., 2012). But to what extent similar patterns of treatment-induced recovery emerge in these two grammatical categories remains unclear. Several single-subject studies and case series have implemented semantic-based treatment targeting verb retrieval in bi/multilinguals with aphasia (Ansaldo et al., 2010; Goral et al., 2012; Knoph et al., 2015, 2017; Li et al., 2020). In general, findings from these studies mirror previous studies targeting nouns, indicating significant improvement in the trained verbs with varying patterns of within- and cross-language generalizations across individuals (Knoph et al., 2017; Lerman et al., 2019; Li et al., 2020).

Although similar findings have been reported among studies training either nouns or verbs, none have directly compared treatment effects between these grammatical categories. Knowing whether the treatment effect differs by a specific grammatical category is essential for developing treatment guidelines for individuals with lexical retrieval difficulties. Three studies to date have trained both nouns and verbs in bi/multilinguals with aphasia (Ansaldo et al., 2010; Goral et al., 2012; Miertsch et al., 2009). In the first study (Miertsch et al., 2009), a German-English-French trilingual with aphasia was trained in the third language (French), targeting lexical-semantic processing. Treatment effect was captured via subtests of the Bilingual Aphasia Test (Paradis, 1987) in all three languages. This participant demonstrated significant improvement in word production in L3 (French) and L2 (English). In another study (Goral et al., 2012), a Spanish-German-French-English multilingual with aphasia received two phases of treatment targeting verb and noun retrieval, one in Spanish and one in English. Significant gains in noun and verb naming were reported following both treatment phases. Another study targeted verb and noun retrieval in a Spanish-English bilingual with pathological switching (Ansaldo et al., 2010). Results showed significant improvements in both word categories in the trained language (Spanish) but no generalization to the untrained language (English). Altogether, results from these three studies pointed to a robust treatment gain targeting either verbs or nouns. Nevertheless, none of them have investigated patterns of treatment-induced recovery as a function of grammatical category.

As mentioned above, evidence of bilingual aphasia rehabilitation has been chiefly derived from Indo-European languages (i.e., Spanish-English, French-English). It is important to examine the treatment effect between nouns and verbs in bilinguals speaking typologically different languages, i.e., Mandarin-English. Concretely, Mandarin is a "verb-friendly" language in which verbs do not carry rich morphosyntactic structures as verbs in English (Gentner, 2006; Vigliocco et al., 2011). In addition, verbs in Mandarin are in a more salient position than nouns, given that pronouns can be dropped in a Mandarin sentence (Huang, 1989). Hence, one would assume different patterns of treatment-induced language recovery between Mandarin and English. To date, one study has examined the effect of naming therapy in Mandarin-English BWA (Li et al., 2020). In this study, two Mandarin-English BWA received a semantic-based treatment in their L1 (Mandarin) targeting verb retrieval. While positive treatment effects and generalizations were reported in both participants, evidence was limited to a small sample size.

Improvement beyond the word level can further promote communication in individuals with aphasia. Nevertheless, generalization of treatment gains to sentence and discourse production have not been systematically investigated across studies in BWA. Among the few studies that have attempted to assess this generalization effect, significant improvements in sentence and discourse production have been reported following verb therapy (Goral et al., 2012; Knoph et al., 2015; Knoph et al., 2017; Lerman, 2020; Lerman et al., 2019; Li et al., 2020). These findings suggest that treatment targeting verb retrieval may promote greater generalization beyond the single-word level as compared to noun treatment.

In sum, previous studies implementing treatment approaches based on lexical-semantic models have consistently reported a direct treatment gain with varying generalization patterns across BWA. Yet, the bulk of research has been limited to noun treatment, and only a few studies have attempted to investigate the effect of verb treatment in bi/multilinguals with aphasia. Although similar findings have been reported among studies targeting either nouns or verbs, to what extent patterns of treatment-induced language recovery are similar in both noun and verb treatment remains unclear. To better understand whether treatment effects are modulated by a specific grammatical category, the same treatment steps need to be implemented for nouns and verbs so that treatment effects can be examined as a function of grammatical category. Most evidence of bilingual aphasia rehabilitation has stemmed from Indo-European languages, whereas little is known if similar patterns of treatment-induced language recovery emerge in bilinguals speaking typologically dissimilar languages. One study has reported positive treatment gains and remarkable generalizations in Mandarin-English BWA, but evidence is limited to two individuals (Li et al., 2020). Therefore, the current study aimed to grow the evidence base for bilingual aphasia rehabilitation by investigating patterns of treatment gains and generalizations between training verbs and nouns in a larger sample of Mandarin-English BWA. Results from this study would allow us to understand bilingual language recovery across different grammatical categories.

5.2 The current study

The primary goal of the study was to directly compare treatment-induced recovery patterns between training nouns and verbs via the implementation of the same treatment steps for both noun and verb treatment. Specifically, we addressed the following aims:

1. To what extent do differences in *treatment acquisition, within-language, and cross-language generalizations* emerge between training nouns and verbs in Mandarin-English BWA?
2. To what extent do *differences* in *generalizations to sentence and discourse production* emerge between training nouns and verbs in Mandarin-English BWA?
3. To what extent do *differences in untrained naming* emerge between training nouns and verbs in Mandarin-English BWA?

Previous studies examining the effect of naming treatment in BWA have identified positive treatment gains, within-language and cross-language generalizations when targeting either nouns or verbs (Edmonds & Kiran, 2006; Kiran et al., 2013; Lerman et al., 2019; Li et al., 2020). Hence, it was hypothesized that Mandarin-English BWA would show significant improvement in naming the trained and semantically-related untrained items in both languages regardless of the target word category (Ansaldo et al., 2010; Goral et al., 2012). Alternatively, training verbs was hypothesized to show more improvement than training nouns. Since verbs may be more impaired than nouns given their weaker connections at the semantic representation level (Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007; Faroqi-Shah & Waked, 2010; Kambanaros, 2010; Dai et al., 2012), training verbs via strengthening the semantic network would enhance lexical access to a larger extent than training nouns.

It was also hypothesized that Mandarin-English BWA would show significant improvement in sentence and discourse production after both noun and verb treatment, but to a greater extent following verb treatment. This hypothesis was supported by previous studies that have consistently reported a generalization effect in sentence and discourse production following verb therapy (Goral et al., 2012; Knoph et al., 2015; Knoph et al., 2017; Lerman, 2020; Lerman et al., 2019; Li et al., 2020). In addition, prior research has suggested a priming effect from verbs to their thematic roles (Ferretti et al., 2001; McRae et al., 2005). Hence, training the target verb was hypothesized to activate nouns associated with its thematic roles, leading to significant gains in sentence and discourse production in Mandarin-English BWA. The alternative hypothesis was that both noun and verb treatment would show a similar effect of generalization beyond the single-word level. Since prior research has pointed out that the priming effect between verbs and their thematic roles can be bidirectional (McRae et al., 2005), targeting either nouns or verbs would enhance lexical access to all syntactic structures, i.e., subject, verb, and object.

Mandarin-English BWA were further expected to improve on naming untrained items following both noun and verb treatment. Specifically, it was hypothesized that noun treatment would facilitate generalization to untrained nouns and verb treatment would promote generalization to untrained verbs (Lerman et al., 2019; Li et al., 2020). Training verbs was also hypothesized to show a greater generalization than training nouns, given that the target verb can activate its thematic roles (McRae et al., 2005). Alternatively, the magnitude of this generalization effect was expected to be similar in noun and verb treatment, as prior research has identified noticeable improvement in untrained naming tasks following either noun or verb treatment (Gil & Goral, 2004; Knoph et al., 2015, 2017; Li et al., 2020).

5.3 Methods

5.3.1 Participants

Twelve Mandarin-English bilinguals with chronic aphasia were enrolled in the current study (Table 5.1; 6 females, mean age = 52.6 ± 18.5 years, mean years of education: 17.7 ± 3.4, mean months post-onset: 51.4 ± 48.4, L1: Mandarin). Eleven of these patients had a single left-hemisphere stroke, and one had a traumatic brain injury (P4). These individuals met the following inclusion criteria: (1) frequently used Mandarin and English before onset, (2) diagnosed with aphasia based on the Western Aphasia Battery-Revised (WAB-R; Kertesz, 2007) for English and the Aphasia Battery in Chinese (ABC; Gao, 1993, 1996) for Mandarin, (3) were between 18 and 85 years old, (4) presented with normal/near normal or corrected-to-normal hearing and vision, (5) were premorbid right-handed, and

(6) had no other neurological condition (i.e., dementia) or learning disorders. Participants were recruited from local and national hospitals, rehabilitation centers, and aphasia support groups. All enrolled participants gave consent according to the Boston University Institutional Review Board protocol.

Individual differences in lexical processing can be influenced by developmental and contextual factors such as L2 age of acquisition (AoA), the degree of life-time exposure to each language, and the frequency of use of each language (Kastenbaum et al., 2019). Therefore, information about second language acquisition and the language use was collected via the Language Use Questionnaire (LUQ; Kastenbaum et al., 2019). This is a self-reported questionnaire that includes six sections: (1) exposure, (2) confidence, (3) daily use, (4) family proficiency, (5) educational history, and (6) self-rating of language ability. Exposure is further broken down into exposure for hearing, speaking, and reading, and the confidence section includes self-confidence in hearing, speaking, and reading. Daily use is separated into input, output, and total use. Family proficiency is also divided into proficiency of mother, father, and siblings. Educational history and self-rating of language ability are not broken down further. Ratings were reported for Mandarin and English separately for all these factors (Table 5.1).

Table 5.1. Patient demographics, language use history, and treatment assignment.

ID	**Sex**	**Age (yr)**	**Edu (yr)**	**MPO**	**AoA**	**Usage %**		**Exposure %**		**LAR %**		**Tx Lang**	**Tx Assignment**
						L1	L2	L1	L2	L1	L2		
P1	F	75.2	18.0	110.8	16.0	4.4	95.6	32.9	67.1	100.0	100.0	C	N → V
P2	M	72.7	20.0	165.2	10.0	33.4	66.6	19.5	80.5	100.0	100.0	C	N → V
P3	M	31.5	25.0	45.0	10.0	43.9	56.1	63.3	36.7	100.0	80.0	E	N → V
P4	F	29.3	17.0	19.2	8.0	0.0	100.0	39.2	60.8	100.0	100.0	C	N → V
P5	F	67.9	13.0	20.8	17.0	22.5	77.5	47.0	53.0	100.0	68.6	E	N → V
P6	F	25.2	20.0	8.2	9.0	56.6	43.4	74.1	25.9	100.0	68.6	E	N → V
P7	M	57.9	20.0	77.3	10.0	19.5	80.5	70.7	29.3	100.0	80.0	C	V → N
P8	M	42.8	16.0	17.4	12.0	50.0	50.0	80.2	19.8	100.0	60.0	C	V → N
P9	F	61.7	19.0	75.5	13.0	36.9	63.1	50.9	49.1	100.0	100.0	E	V
P10	F	53.0	15.0	20.5	12.0	29.2	70.8	43.6	56.4	88.6	82.9	E	V
P11	M	38.7	16.0	50.1	12.0	32.0	68.0	23.1	76.9	90.0	100.0	E	N
P12	M	74.7	13.0	6.2	20.0	50.0	50.0	80.8	19.2	100.0	48.6	E	N
Mean		**52.6**	**17.7**	**51.4**	**12.4**	**31.5**	**68.5**	**52.1**	**47.9**	**98.2**	**82.4**		
SD		**18.5**	**3.4**	**48.4**	**3.6**	**17.7**	**17.7**	**21.5**	**21.5**	**4.2**	**18.1**		

Edu: education; MPO: months post-onset; AoA: age of acquisition; LAR: language ability rating; Tx: treatment; Lang: language; F: female, M: male; L1: Mandarin, L2: English; N → V: noun treatment then verb treatment; V → N: verb treatment then noun treatment; C: Mandarin Chinese, E: English.

5.3.2 Experimental design

A cross-over experimental treatment design was implemented across participants. Among the twelve Mandarin-English BWA (Table 5.1), eight participants completed a two-cycle treatment (P1 – P8), one for verbs and one for nouns. They received either noun treatment followed by verb treatment or verb treatment followed by noun treatment. The other four participants (P9 – P12) completed a one-cycle treatment targeting either nouns or verbs. For each participant, the same language (either Mandarin or English) was trained for all treatment cycles, counterbalanced across participants. Hence, a total n = 5 participants were assigned to each of the four treatment conditions: (1) English noun, (2) English verb, (3) Mandarin noun, and (4) Mandarin verb.

A multiple baseline approach (Connell & Thompson, 1986) was implemented for each treatment cycle, including a baseline phase, a treatment phase, and a post-treatment phase (Figure 5.1). For those who completed both treatment cycles, an average of 4 – 6 weeks of washout was added between each cycle[1].

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[1] The wash-out period for P3 and P4 was four and six months respectively due to health and personal reasons.

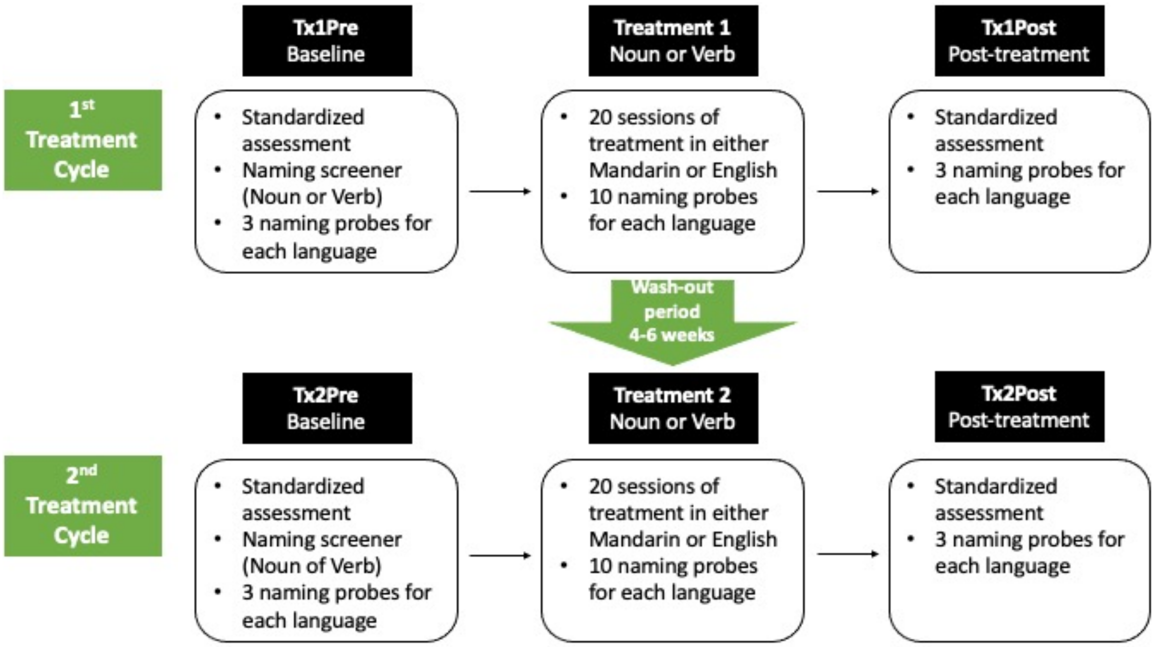

Figure 5.1. Within-subject treatment design. Tx1Pre: pre-treatment of the 1st treatment cycle, Tx1Post: post-treatment of the 1st treatment cycle, Tx2Pre: pre-treatment of the 2nd treatment cycle, Tx2Post: post-treatment of the 2nd treatment cycle.

5.3.3 Standardized language assessments and scoring

Before and after each treatment cycle (i.e., Tx1Pre, Tx1Post, Tx2Pre, Tx2Post), participants were administered a battery of standardized language assessments and discourse tasks that were counterbalanced by language across testing sessions. Previous studies comparing in-person and teleassessment have reported no significant difference in performance between these two modalities (Dekhtyar et al., 2020; Theodoros et al., 2008). Hence, all the assessments in this study were conducted remotely via Zoom (https://zoom.us/) during the COVID-19 pandemic. Scores were calculated based on guidelines within each test manual and aimed to characterize language impairment in both languages comprehensively.

WAB-R and ABC

The WAB-R (Kertesz, 2007) and the ABC (Gao, 1993, 1996) were administered to measure the overall aphasia severity in English and Mandarin, respectively, as characterized by the Aphasia Quotient (AQ). The ABC is a Chinese-adapted version of the WAB-R. Previous studies have indicated its high reliability and validity based on assessment outcomes from 199 post-stroke patients with aphasia and 165 post-stroke patients without aphasia (Gao, 1993, 1996). Improvement was considered clinically significant for the overall aphasia severity if scores improved more than 5.03 points on the AQ (Gilmore et al., 2019; Katz & Wertz, 1997).

Boston Naming Test

Single-word lexical retrieval in English was evaluated with the Boston Naming Test Long Form (BNT; Kaplan et al., 2001), containing pictures of 60 common objects. A 30-item version for the Chinese BNT (Chen et al., 2014; Cheung et al., 2004) was administered to assess the noun-retrieval ability in Mandarin Chinese. This 30-item BNT has been culturally adapted and validated in Chinese speakers. A cut-off score of 24 in spontaneous naming generated a sensitivity of 73.1 and specificity of 75.3 in differentiating normal from participants with brain injury (Cheung et al., 2004), suggesting that the 30-item BNT applies to the Chinese-speaking population.

Northwestern Naming Battery & Northwestern Assessment of Verbs and Sentences

Confrontation naming of nouns and verbs was additionally administered using the Northwestern Naming Battery (NNB; Thompson et al., 2012) and the Verb Naming Test (VNT) from the Northwestern Assessment of Verbs and Sentences (NAVS, Thompson, 2012). For the NNB, items that comprised the noun-verb ratio were administered (n = 16 each for nouns and verbs). The same subtests were administered using the Chinese NNB (Gao et al., 2016) and NAVS (Wang & Thompson, 2016).

Verb retrieval in sentences was also assessed via the Argument Structure Production Test (ASPT) from the NAVS (Thompson, 2012). Following the procedures in previous verb treatment studies (Edmonds et al., 2009; Li et al., 2020), the target verb was not shown to participants in the ASPT. The VNT and ASPT of the NAVS-Chinese (Wang & Thompson, 2016) were administered to assess verb retrieval in single-word naming and sentence production in Mandarin.

All sentences in the ASPT were further coded for the following measures to address aim 3: (1) a complete utterance (CU; 0 = incomplete, 1 = complete; Edmonds et al., 2009; Hoover et al., 2021; Lerman et al., 2019), (2) verb production (0 = inaccurate, 1 = accurate), (3) proportion of argument production, i.e., agent and/or patient(s), and (4) a rating scale capturing the accuracy and completeness of an utterance.

CU. A CU was scored based on two criteria: (a) whether an utterance was relevant to the context (± REL) and (b) whether it included an appropriate agent, verb, and patient, if necessary (± SVO). An utterance was scored complete if both criteria were met. Responses were still credited with the following errors: grammatical errors (i.e., target: "the dog is barking", response: "the dog bark is"), morphological errors (e.g., target: "the dog is barking", response: "the dog are barking"), less than 50% of phonemic errors per lexical item (e.g., target: "the man is driving", response: "the ban is diving"), and cross-linguistic errors (e.g., target: "the man is driving", response: "男人 is driving").

Verb and argument production. A binary score of 0 (inaccurate) or 1 (accurate) was assigned to each verb and its argument(s). A score of 1 was credited for the following responses: (a) the target word in either the target or non-target language, (b) less than 50% of phonemic errors per lexical item (e.g., target: "shave", response: "rave"), and (c) synonyms (e.g., target: "package", response: "box"). Percent argument production was then calculated based on equation (5-1).

$$\frac{\#\ of\ correct\ arguments}{total\ \#\ of\ arguments} \qquad \textit{Equation (5-1)}$$

Scale. An accumulative scale between 0 – 5 was rated for responses: (1) obtained, (2) produced in the target language, (3) included the target verb, (4) semantically accurate, and (5) grammatically accurate.

Pyramids and Palm Trees Test

A three-picture version of the Pyramids and Palm Trees Test (PPT; Howard & Patterson, 1992) was administered to evaluate semantic processing in Mandarin-English BWA. This test was administered in the dominant or preferred language, given that bilinguals have a shared semantic system across languages (Kroll & Stewart, 1994).

Cognitive Linguistic Quick Test

Executive functions were assessed using the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, 2001). This domain included three non-linguistic tasks (i.e., symbol trails, mazes, design generation) and one linguistic task (i.e., generative naming). Previous studies have suggested different mechanisms for processing language control and general cognitive control in BWA (Gray & Kiran, 2016). Hence, all the non-linguistic tasks were assessed in the dominant or preferred language, and the linguistic tasks were evaluated in both languages.

Discourse

Connected speech samples were collected in Mandarin and English in separate sessions using sequential-picture, single-picture, and storytelling tasks from the AphasiaBank (*https://aphasia.talkbank.org/*), which have been commonly implemented for assessing spontaneous speech for both clinical and research purposes (Chen et al., 2018; MacWhinney et al., 2011). Performance may vary across these tasks as they elicit distinctive linguistic and cognitive demands (Brady et al., 2005; Nicholas & Brookshire, 1993). The sequential pictures included a six-frame strip ("*Umbrella"*) that depicts the story of a young boy who refuses to take an umbrella from his mother when he leaves for school; on his way to school, it starts raining, so he returns home to take the umbrella. The single picture was *"Cat Rescue"* (Nicholas & Brookshire, 1993). In this picture, a girl's cat is on a tree, and her dad has tried to rescue the cat but is stuck on the tree; so the fire department comes to rescue the cat and the girl's father. The single- and sequential-picture stimuli were included in Appendix A Figure 1 and can be found at: *www.talkbank.org/AphasiaBank/protocol/pictures.html*. Storytelling was assessed using *"The Tortoise and the Hare,"* which is about a hare falling asleep while running a race with a tortoise, then the tortoise wins the race. This story was chosen because it is culturally relevant to the Chinese population than other stories such as *"Cinderella"* (Kong, 2017). Responses in these discourse tasks were video recorded and transcribed by the first author using the Computerized Language ANalysis (CLAN) program (MacWhinney, 2000).

All narratives were coded for the following measures using the Computerized Quantitative Production Analysis (C-QPA) command (Berndt et al., 2000; Saffran et al., 1989): (1) number of CUs (see above for the scoring criteria; Edmonds et al., 2009; Hoover et al., 2021; Lerman et al., 2019), (2) number of utterances, (3) number of narrative words, (4) number of nouns, and (5) number of verbs. The primary outcome measure was total numbers of words (i.e., narrative words, nouns, and verbs), which have been previously applied to capture generalization to discourse production following naming treatment (Dai et al., 2012). The secondary outcome measure was the total number of CUs, given its clinical applicability and high sensitivity to generalization effects (Edmonds et al., 2009; Lerman et al., 2019; Li et al., 2020).

5.3.4 Stimuli

Naming screener for nouns and verbs

A naming screener of either nouns or verbs was administered at pre-treatment to help select treatment and control stimuli. The category of the screener corresponded to the treatment target, i.e., a screener of nouns was administered before noun treatment, and a screener of verbs was administered before verb treatment.

A total of 298 object pictures were included in the noun screener. Items were selected based on Sandberg et al. (2020), in which semantic features were validated for over 600 items across a variety of semantic categories (e.g., birds, animals, clothing, foods, furniture, etc.). Nouns with validated features were matched with semantically-related items based on Princeton University's WordNet database (http://wordnetweb.princeton.edu).

The verb naming screener comprised 230 action pictures for transitive and intransitive verbs. Items were selected from the International Picture Naming Project (IPNP; Szekely et al., 2004) which includes actions that have been normed across a variety of languages (Arévalo et al., 2011; Szekely et al., 2005). Items with validated features based on Buchanan et al. (2019) were matched with semantically-related items following the same procedure as described for nouns. All nouns and verbs were then directly translated into Mandarin Chinese and verified by a native Mandarin speaker.

Naming screeners were administered in language blocks. Stimuli were pseudo-randomized to ensure that semantically-related items (e.g., "*eat"* and "*drink"*) were not presented sequentially. Verbal instructions were conveyed in the same language as the target language (Appendix B). The following responses were scored as accurate: (1) the target response in the target language, (2) dialectal variants, (3) no more than one phonemic error, i.e., substitutions (e.g., target: "coat", response: "foat"), omissions (e.g., target: "eat", response "ea"), and additions (e.g., target: "whale", response: "pwhale"), (4) in plural or tense (e.g., target: "orange", response: "oranges"; target: "drink", response: "drinking"), and (5) synonyms (e.g., target: "bucket", response: "pail"). A score of 0 was given for the following responses: (1) unintelligible, (2) cross-linguistic errors (e.g., target: "scarf", response: "围巾"), (3) more than one phonemic error (e.g., target: "sparrow", response: "pallow"), or (4) no responses.

Treatment and control stimuli

Inaccurate items in both languages from noun and verb naming screeners were selected for treatment and control stimuli, which also served as naming probes for verb and noun treatment (see Appendix A Table 1 for sample stimuli). For each participant, six 15-item sets were selected for nouns: (1) English Set 1 (ESN1), (2) Mandarin translation of ESN1 (MSN1), (3) English Set 2, semantically-related to Set 1 (ESN2), (4) Mandarin translation of ESN2, (MSN2), (5) English Set 3, unrelated/control items (ESN3), (6) Mandarin translation of ESN3 (MSN3). Another six 15-item sets were chosen for verbs: (1) English Set 1 (ESV1), (2) Mandarin translation of ESV1 (MSV1), (3) English Set 2, semantically-related to Set 1 (ESV2), (4) Mandarin translation of ESV2 (MSV2), (5) English Set 3, unrelated/control set (ESV3), (6) Mandarin translation of ESV3 (MSV3). Set 1 items in either English or Mandarin were used for treatment, depending on the assigned language. Cognates were excluded given their potential cross-linguistic facilitation effect (Costa et al., 2005), i.e., words overlapped by more than 50% of phonemes across Mandarin and English (e.g., *mango* in English and *mang-guo* in Mandarin). Picture stimuli from naming screeners were used for treatment.

Psycholinguistic measures were further obtained to match stimuli within participant[2] and to account for their potential influence on treatment responses. Specifically, frequency-per-million was extracted from the *SubtlexUS* for English (Brysbaert & New, 2009) and from the *Subtlex-CH* for Mandarin Chinese (Cai & Brysbaert, 2010). In addition, the number of syllables, lexical familiarity and imageability values were extracted from Glasgow Norms (Scott et al., 2019) and the MRC Psycholinguistic Database (Coltheart, 1981). Ratings of familiarity and imageability are based on 7-point scales (lower means

[2] Stimuli were not matched across participants given that not all participants were enrolled at the same time.

less familiar or imageable). Since values of most stimuli are unavailable in the existing Chinese databases (Liu et al., 2007; Wang & Chen, 2020; Xu et al., 2021), imageability and familiarity ratings in English were used as approximate measures for all Mandarin stimuli. Previous studies have reported high correlations of imageability ratings across languages, suggesting that lexical-semantic ratings may be used cross-linguistically (Blomberg & Öberg, 2015; Rofes et al., 2018).

For each participant, separate linear regression models were conducted to match word frequency and number of syllables for items that were: (1) between languages for each set (e.g., MSN1 and ESN1), and (2) across sets for each language (e.g., MSN1, MSN2, and MSN3; fixed factor: set*language interaction term). There was no significant difference between languages by set (p-values > 0.05) or across sets by language (p-values > 0.05) for all participants. Within each participant who completed both noun and verb treatment (i.e., P1 – P8), word frequency and number of syllables were further matched between nouns and verbs: (1) within and between languages by set (e.g., MSN1 and MSV1; MSN1 and ESV1), and (2) across sets by language (e.g., MSN1 and MSV2; ESN2 and ESV3; fixed factor: set*language*word class three-way interaction). Results did not reveal any significant differences between verbs and nouns within- and between-language by set (p-values > 0.05) or across sets by language (p-values > 0.05) for all participants but P3 (number of syllables: ESN1 > ESV1, $p < 0.05$).

Semantic features

Feature validation for noun stimuli was based on five labels: *category* (i.e., it belongs to), *characteristic* (i.e., it has, or it is), *physical attribute* (i.e., it looks like), *function* (i.e., it is used for), and *location* (i.e., where it can be found; Edmonds & Kiran, 2006; Kiran et al., 2013; Kiran & Iakupova, 2011; Kiran & Roberts, 2010; Krishnan et al., 2014; Sandberg, Chaleece; Gray, Teresa; Kiran, 2020). Specifically, English-speaking MTurk participants (not included in the current study) verified: (1) whether a word matched with the picture and, if not, to provide the correct label, and (2) whether the given features (e.g., "can fly") applied to the target word (e.g., "vulture"). A vector of numerical features was built for each word encoded the percentage of MTurk participants who verified that a given feature applied to the target word. Features that more than 50% of the participants agreed upon were coded as "yes" (i.e., matched with the target), and those that less than 50% of the participants agreed upon were coded as "no" (i.e., did not match with the target)[3]. At least six features each for "yes" and "no" categories were assigned to each trained item (see Appendix A Table 2 for sample features)[4]. Feature labels were assigned to the applied features based on the noun SFA treatment protocol: (1) function, (2) characteristics, (3) physical attributes, (4) category, and (5) location.

Semantic features for verbs were extracted from Buchanan et al. (2019). Verbs in this database denote various events, including the manner of motion, light emission, contact, exchange, communication, sounds, body motion, and sensation (Vinson & Vigliocco, 2008). Features were collected from either MTurk participants (Buchanan et al., 2019) or ungraduated students (Vinson & Vigliocco, 2008), who were asked to produce the properties or features of each given concept in areas including physical (i.e., looks, sounds,

[3] Ambiguous features (i.e., 50% agreement) were determined based on participants' judgement.
[4] For items that features were unavailable, at least six features each for "yes" and "no" categories were selected from their semantically-related items.

and feels), functional (i.e., uses), location (i.e., where it comes from) and categorical (i.e., belongings)[5]. Features in Buchanan et al. (2019) were listed by at least 16% of participants or were in the top five features listed for the given target. In the current study, each trained item was assigned at least six features for both "yes" and "no" categories (see Appendix A Table 3 for sample features). Feature labels were then assigned to the applied features based on the verb SFA treatment protocol: (1) subject, (2) purpose/object, (3) physical attributes, (4) how, and (5) location. All the features were directly translated into Mandarin Chinese and verified for accuracy.

5.3.5 Procedures

Baseline

Three consecutive sessions of probe testing were administered in both languages at the beginning of each treatment cycle. All the probe stimuli for the target word category (i.e., six 15-item sets, total n = 90) were presented in language blocks, counterbalanced across sessions (i.e., baseline session 1: English 1st, Mandarin 2nd; baseline session 2: Mandarin 1st, English 2nd; baseline session 3: English 1st, Mandarin 2nd). Stimuli were pseudo-randomized in each probe to ensure that: (1) two semantically-related items were not presented sequentially and (2) no more than two items from the trained set (i.e., ESN1, MSN1, ESV1, MSV1) were presented sequentially.

Treatment and post-treatment probes

During the treatment phase, the same 90-item naming probes in both languages

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[5] Conjoint features (e.g., "*red fruit*" or "*four legs*") were treated as two separate features in this database. To facilitate better interpretation, single-word features were modified with descriptive phases (e.g., "it is…/it has…").

were administered at the beginning of every other treatment session (n = 10 per language). In addition, three post-treatment probes for both languages were administered immediately following the treatment phase. Verbal instructions and scoring criteria followed the same as described for naming screeners. Responses were audio and video recorded for data analysis.

Treatment materials and administration

In each treatment cycle, participants received two-hour sessions twice per week for ten weeks (total = 40 hours per cycle). One treatment cycle was terminated after all 20 sessions were completed. Treatment was conducted by the first author and trained research assistants, who are all fluent speakers of both Mandarin and English. All treatment sessions were conducted online via Zoom during the COVID-19 pandemic.

Fifteen treatment stimuli (i.e., Set 1 items) were randomized across 20 sessions in each treatment cycle. Treatment was delivered via PsychoPy3 (Peirce, 2007) on Pavlovia (https://pavlovia.org/).

Treatment steps

The treatment steps for delivering noun therapy followed previous bilingual aphasia studies (Edmonds & Kiran, 2006; Kiran & Roberts, 2010; Kiran et al., 2013; Sandberg et al., 2020). The same steps were adapted for verbs based on the verb SFA treatment protocol (Wambaugh & Ferguson, 2007b). A total of six steps were administered for each target word: (1) spontaneous naming, (2) feature selection and assignment, (3) word association, (4) feature verification, (5) spontaneous naming, and (6) sentence production (see Appendix C for details).

Treatment reliability

To ensure the reliability of treatment administration, two trained research assistants conducted a fidelity check for 25% of all the videotaped sessions. Point-by-point inter-rater reliability between raters one and two was further performed for 20% of their rated sessions using *Pearson's* correlations.

5.3.6 Data analysis

Descriptive and statistical analyses were conducted to address each research aim. All analyses were performed in R Studio (version 4.0.3). Statistical significance was set at $p < 0.05$.

Treatment gain, within- and cross-language generalization

Probe responses in all treatment phases (i.e., baseline, treatment, post-treatment) served as the primary outcome measure for this aim. Group-level analysis was conducted to investigate the potential treatment efficacy and efficiency. Given that recovery patterns may vary across participants, individual effect sizes were further calculated to allow for the examination of treatment-induced recovery patterns without the influence of individual variability.

To capture treatment effects in noun treatment, generalized linear mixed-effects models (GLMM) were conducted to estimate the direct treatment gain and within-language generalization in the treated language (Model 1), and cross-language generalization in the untreated language (Model 2). In Model 1, the item-level accuracy for the treated language was the dependent variable (0 = inaccurate, 1 = accurate). Fixed factors included probe session (i.e., probe 1, probe 2, etc.), item set (i.e., SN1, SN2, SN3), and a session*set interaction term. The WAB-AQ was included as a covariate. Random structures included random intercepts for subject and item and by-subject and by-item random slopes for session. In Model 2, the item-level accuracy in the untreated language was the dependent variable. Fixed factors and random structures were the same as in Model 1. To assess treatment effects in verb treatment, the previous two models were repeated with the item-level response accuracy for verbs being the dependent variable (Models 3 and 4). Model structures were the same as above.

Two additional GLMMs were performed to examine treatment effects between training nouns and verbs in the treated (Model 5) and the untreated (Model 6) language. In each model, the item-level accuracy across all stimuli (i.e., nouns and verbs) was the dependent variable (0 = inaccurate, 1 = accurate). The independent variables included probe session (i.e., probe 1, probe 2, etc.), item set (i.e., SN1, SN2, SN3, SV1, SV2, SV3), treatment category (i.e., nouns, verbs), and a session*set*category three-way interaction. The treatment order (i.e., 1 = first treatment, 2 = second treatment) and WAB-AQ were entered as covariates. Random intercepts for item and subject and by-item and by-subject random slopes for session were also included.

Individual effect sizes (ES) were calculated using the Cohen's *d* statistic (Cohen, 1988; equation 5-2; M was the mean response accuracy, σ was the standard deviation) for each set of stimuli (i.e., MSN1, MSN2, MSN3, MSV1, MSV2, MSV3; ESN1, ESN2, ESN3, ESV1, ESV2, ESV3). When the pre-treatment standard deviation (SD) was 0, the pooled SD from the other two sets of stimuli was calculated instead (equation 5-3). Benchmarks of 2.3 (small), 3.7 (medium), and 5.5 (large) were used for the trained stimuli (Edmonds, 2014; Li et al., 2020), and benchmarks of 1.2 (small), 1.7 (medium), and 3.3 (large) were used for the untrained stimuli, i.e., control items, semantically-related items, and all translation items (Edmonds et al., 2014; Li et al., 2020).

$$d = \frac{(M_{post} - M_{pre})}{\sigma_{pre}} \qquad \textit{Equation (5-2)}$$

$$SD_{pooled} = \sqrt{\frac{SD_1^2 + SD_2^2}{2}} \qquad \textit{Equation (5-3)}$$

Generalization to sentence and discourse production

To estimate generalization to sentence production, responses from the ASPT of the NAVS in both Mandarin and English were included in the current analysis (n = 20 items in Mandarin, n = 22 items in English)[6]. Mixed-effects models were conducted to estimate responses in the treated and untreated languages separately. Dependent measures included CUs, verb production, percent argument production, and rated scale (Table 5.2). Fixed and random factors were the same across all the models.

Table 5.2. Model structures estimating treatment generalization to sentence production.

	CU	**Verb production**	**Argument production**	**Rating scale**
Model	GLMM	GLMM	LMM	CLMM
Dependent measure	0 (incomplete) or 1 (complete)	0 (inaccurate) or 1 (accurate)	Proportion of accurate argument (%)	Scale between 0 and 5
Fixed factors	Time point: pre, post Treatment category: noun, verb Time*Category interaction			
Random structure	By-subject and by-item random intercepts			
Covariates	WAB-AQ, treatment order (i.e., 1st or 2nd)			

[6] Twelve items in the English ASPT included the same target verb but optional argument structure (i.e., "the man drives the car" and "the man drives"). Hence, redundant items were excluded from the analysis.

Note: Same models were conducted for both treated and untreated languages. CU: complete utterance; GLMM: generalized linear mixed-effects model; LMM: linear mixed-effects model; CLMM: cumulative link mixed-effects model; WAB-AQ: Western Aphasia Battery Aphasia Quotient.

To estimate generalization to discourse production, responses from all the discourse tasks (i.e., *Cat Rescue, Umbrella, The Tortoise and the Hare*) were included in the analysis. Mixed-effects models were conducted to estimate the generalization effect to discourse production in the treated and untreated languages separately. Dependent measures included total counts of narrative words, nouns, verbs, utterances, and CUs across all discourse tasks (Table 5.3). Fixed and random factors were the same for all these models.

Table 5.3. Model structures estimating treatment generalization to discourse production.

	Narrative words	**Verb production**	**Noun production**	**Utterance**	**CU**
Model	Poisson GLMMs				
Dependent measure	Total # of narrative words	Total # of verbs	Total # of nouns	Total # of utterances	Total # of CUs
Fixed factors	Time point: pre, post Treatment category: noun, verb Time*Category interaction				
Random structure	By-subject random intercept				
Covariates	WAB-AQ, treatment order (i.e., 1st or 2nd)				

Note: Same models were conducted for both treated and untreated languages. CUs: complete utterances; GLMM: generalized linear mixed-effects model; WAB-AQ: Western Aphasia Battery Aphasia Quotient.

Inter-rater reliability check. Twenty percent of the narratives was randomly assigned to a trained student and transcribed to check for reliability. Inter-rater reliability was calculated for the C-QPA measures (i.e., total numbers of CUs, narrative words, nouns, verbs, and utterances) using *Pearson's* correlations.

Generalization to untrained verbs and nouns

To address the last research aim, responses from standardized naming tasks at all assessment time points were included in the analysis. Specifically, noun stimuli were composed of the same items on the Mandarin and English BNTs (n = 30 per language) and items that contributed to the noun-verb ratio on the NNB (n = 16 per language). Likewise, verb stimuli were composed of non-redundant items from the NNB and the NAVS (n = 21 for Mandarin, n = 31 for English).

Two separate GLMMs were performed to estimate the effect of generalization to noun naming in the treated and untreated languages. The item-level response accuracy for nouns was the dependent measure (0 = inaccurate, 1 = accurate). Fixed factors included time point (i.e., pre, post), treatment category (i.e., nouns, verbs), and a time*category two-way interaction. The WAB-AQ and treatment order (i.e., first, second) were included as covariates. By-subject and by-item random slopes were also included to account for additional variance. Another two GLMMs were conducted to estimate the effect of generalization to verb naming in treated and untreated languages. The dependent measure was the item-level accuracy for verbs. Fixed factors and random structures were the same as the previous models.

5.4 Results

Individual performance on standardized assessments is shown in Appendix D Table 1. Table 5.4 illustrates the group-level performance based on the treatment language (i.e., L1 or L2) in both noun and verb treatment. According to the previously established clinical benchmarks for aphasia rehabilitation (Gilmore et al., 2019), the average WAB-AQ in the treated language improved significantly following noun treatment in L1, i.e., Mandarin (> 5.03 points). In addition, the average BNT score in the treated language increased significantly after verb treatment in L2, i.e., English (> 3.30 points). Although other measures did not reveal significant improvement (paired *t*-tests, *p*-values > 0.05), patterns of gains were still observed in treated and untreated languages, as highlighted in Table 5.4. In general, both noun and verb treatment facilitated gains from pre- to post-treatment in the overall aphasia severity (i.e., WAB-AQ), verb and noun naming (i.e., BNT, NNB, VNT), sentence production (i.e., ASPT), as well as semantic processing (i.e., PPT).

Table 5.4. Group-level performance on standardized assessments by each treatment cycle.

		Noun Tx								**Verb Tx**							
		Tx Lang: L1 (n = 5)				**Tx Lang: L2 (n = 5)**				**Tx Lang: L1 (n = 5)**				**Tx Lang: L2 (n = 5)**			
		Pre		**Post**		**Pre**		**Post**		**Pre**		**Post**		**Pre**		**Post**	
Test	**TL**	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***	***Ms***	***SD***
WAB-AQ	T	**55.6**	**19.2**	**61.9***	**18.4**	81.0	2.6	79.7	1.2	**61.1**	**16.8**	**61.7**	**16.8**	84.2	9.8	83.2	9.4
	U	**52.5**	**29.4**	**54.8**	**29.8**	**84.2**	**5.9**	**86.1**	**7.6**	**55.3**	**31.7**	**57.0**	**30.0**	85.6	4.6	85.5	5.6
BNT Raw	T	**7.6**	**8.3**	**8.0**	**7.9**	**21.6**	**4.0**	**24.3**	**5.6**	**8.0**	**8.2**	**8.8**	**9.1**	**26.2**	**7.0**	**29.8***	**6.6**
	U	15.4	19.4	14.8	20.8	**20.0**	**8.1**	**20.2**	**7.8**	**17.2**	**20.0**	**17.6**	**19.8**	19.8	5.1	19.6	5.5
NNB obj %	T	**38.8**	**34.9**	**57.5**	**27.7**	**78.8**	**12.2**	**83.8**	**7.1**	**45.0**	**38.4**	**50.0**	**28.0**	83.8	9.5	82.5	14.3
	U	48.8	46.4	48.8	45.6	**86.3**	**20.9**	**95.0**	**5.2**	**47.5**	**47.3**	**50.0**	**45.7**	**92.5**	**10.3**	**96.3**	**5.6**
NNB act %	T	**26.3**	**35.2**	**32.5**	**32.0**	**58.8**	**18.0**	**68.8**	**11.7**	**36.3**	**29.4**	**41.3**	**30.2**	**70.0**	**19.5**	**76.3**	**21.4**
	U	**25.0**	**36.2**	**35.0**	**36.6**	**68.8**	**17.1**	**80.0**	**12.8**	**33.8**	**37.1**	**38.8**	**38.6**	87.5	15.9	78.8	16.3
VNT %	T	**21.0**	**37.1**	**28.0**	**38.2**	**57.3**	**9.0**	**68.2**	**9.2**	**29.0**	**37.7**	**33.0**	**32.0**	**69.1**	**9.4**	**80.9**	**19.5**
	U	**30.9**	**41.7**	**39.1**	**40.9**	**71.0**	**7.6**	**74.0**	**5.0**	**34.5**	**41.5**	**41.8**	**41.4**	82.0	5.0	71.0	13.5
ASPT ALL %	T	**25.0**	**33.2**	**42.0**	**35.1**	83.1	14.2	80.6	11.6	**37.0**	**29.0**	**45.0**	**30.5**	87.5	18.6	76.3	18.6
	U	**36.3**	**35.4**	**42.5**	**40.9**	**77.0**	**16.4**	**90.0**	**16.7**	**38.1**	**43.8**	**41.3**	**39.4**	**85.0**	**15.7**	**87.0**	**16.4**
CLQT EF-NV		19.2	6.8	17.5	1.7	22.6	9.2	22.2	10.4	22.4	6.3	21.6	6.4	23.6	9.5	21.8	10.2
PPT %		85.7	9.1	85.0	9.9	**94.4**	**5.8**	**95.0**	**2.8**	**82.8**	**15.8**	**89.1**	**10.4**	95.9	2.4	92.5	7.4

Note: Scores are bolded for higher post- than pre-treatment; *: significant change based on the previous benchmarks. Tx: treatment; L1: Mandarin, L2: English; TL: target language; Pre: pre-treatment, post: post-treatment. Ms: means, SD: standard deviation. WAB-AQ: Western Aphasia Battery Aphasia Quotient (total = 100), its L1 equivalence was obtained via the Aphasia Battery in Chinese Aphasia Quotient (ABC; total = 100); BNT Raw = Boston Naming Test raw score (total = 60 for L2, total = 30 for L1); NNB obj: Northwestern Naming Battery Object Naming (total = 16 in L2 and L1); NNB act: Northwestern Naming Battery Action Naming (total = 16 in L2 and L1); VNT: Verb Naming Test (total = 22 in L2; total = 20 in L1); ASPT ALL: Argument Structure Production Test with all arguments (total = 32 in L2, total = 20 in L1); CLQT EF-NV: Cognitive Linguistic Quick Test Executive Function Non-verbal (total = 31); PPT: Pyramids and Palm Trees (total = 64). CLQT EF-NV and PPT were administered in the dominant language only.

5.4.1 Treatment gain, within- and cross-language generalization

Among the 25% of sessions checked for fidelity, the treatment protocol was followed with a reliability of 99.6% across all participants. Inter-rater reliability between raters 1 and 2 showed a significant correlation ($r = 0.2, p < 0.05$).

Individual performance on naming probes is reported in Appendix D Figure 1. Group-level probe responses in noun and verb treatment are illustrated in Figure 5.2. For noun treatment, mixed-model results in the treated language showed that over time, there was a significant improvement in the trained items (β = 0.45, SE = 0.04, $p < 0.01$) and the semantically-related untrained items (β = 0.07, SE = 0.04, $p < 0.05$). In the untreated language, translations of the trained items also improved significantly over time (β = 0.13, SE = 0.04, $p < 0.01$). These findings suggested a remarkable treatment gain, within-language, and cross-language generalizations when treatment targeted nouns.

For verb treatment, mixed-model results captured a significant improvement of the trained items over time in the treated language (β = 0.50, SE = 0.03, $p < 0.01$), but there was no generalization to the semantically-related items at either the group level ($p > 0.05$) or the individual level (ESs < 1.2). In the untreated language, translations of both trained (β = 0.31, SE = 0.03, $p < 0.01$) and semantically-related items (β = 0.13, SE = 0.03, $p < 0.01$) improved significantly over the course of treatment. These results indicated a significant treatment gain and a cross-language generalization effect when treatment targeted verbs, but no within-language generalization to semantically-related items.

In the model that directly compared treatment effects between nouns and verbs in the treated language, the trained items improved significantly over time to a larger extent in verb versus noun treatment (β = 0.12, SE = 0.05, $p < 0.05$), but generalization to semantically-related items did not significantly differ between training nouns and verbs ($p > 0.05$). In the untreated language, translations of both trained (β = 0.14, SE = 0.05, $p < 0.01$) and untrained items (β = 0.10, SE = 0.05, $p < 0.05$) improved to a greater extent in verb treatment as compared to noun treatment. These findings suggested that training verbs promoted greater treatment gain and cross-language generalization than training nouns in Mandarin-English BWA.

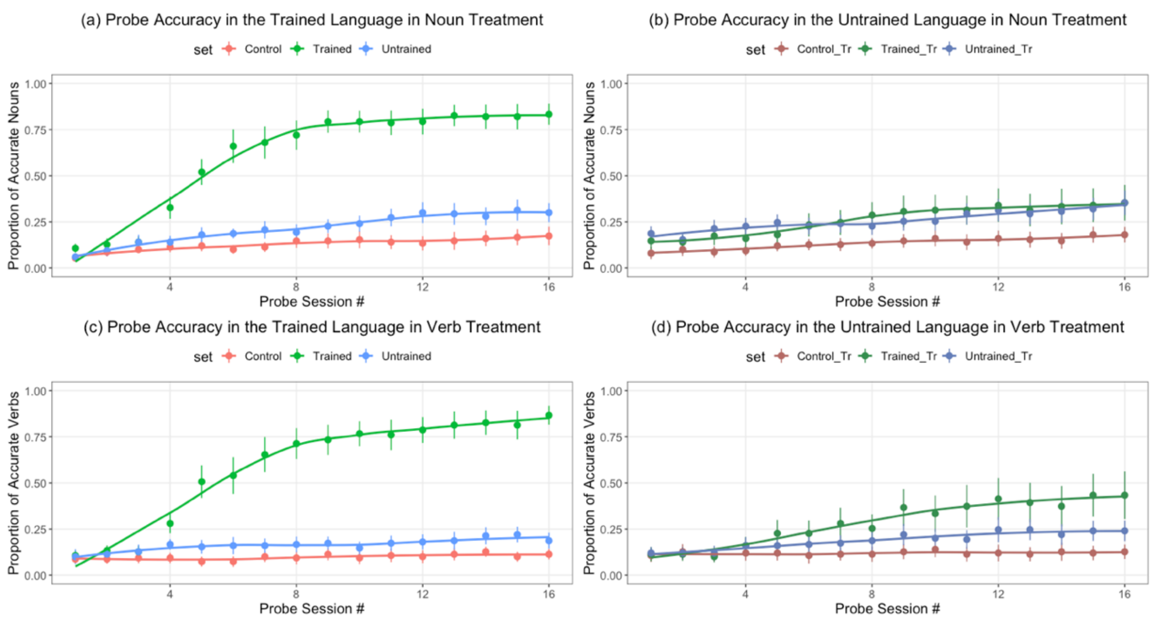


Figure 5.2. Group-level performance on naming probes in the noun and verb treatment. X-axis is probe sessions 1 – 16: 1 – 3 (baseline phase), 4 – 13 (treatment phase), 14 – 16 (post-treatment phase). Y-axis is the average response accuracy (1.00 = 100 %). Control_Tr: translations of control items, Trained_Tr: translations of trained items, Untrained_Tr: translations of semantically-related untrained items.

5.4.2 Generalization to sentence production

Figure 5.3 illustrates the group-level performance on sentence production based on: (a) CUs, (b) target verbs, (c) verb arguments, i.e., nouns, and (d) rating scale. The individual performance captured by the same measures is exhibited in Appendix D Table

3. Mixed-model results did not show any significant improvement in the production of CUs or the target verbs following either noun or verb treatment (p-values > 0.05). Results from the models predicting argument production revealed a significant improvement following noun treatment in both treated ($\beta = 0.12$, SE = 0.02, $p < 0.01$) and untreated ($\beta = 0.04$, SE = 0.02, $p < 0.05$) languages. Another significant gain of argument production was observed in the treated language after verb treatment ($\beta = 0.07$, SE = 0.02, $p < 0.01$). Furthermore, the rating scale captured a significant gain (i.e., sentences were more likely to be accurate) in both treated ($\beta = 0.80$, SE = 0.19, $p < 0.01$) and untreated ($\beta = 0.94$, SE = 0.23, $p < 0.01$) languages following noun treatment. Another significant improvement in the rating scale was found in both treated ($\beta = 0.77$, SE = 0.20, $p < 0.01$) and untreated ($\beta = 0.54$, SE = 0.23, $p < 0.05$) languages after verb treatment. Training nouns and verbs did not show significant differences in the change of any measures. These findings suggested that both noun and verb treatment promoted increased argument production and the overall accuracy of sentence production in the treated and untreated languages in Mandarin-English BWA.

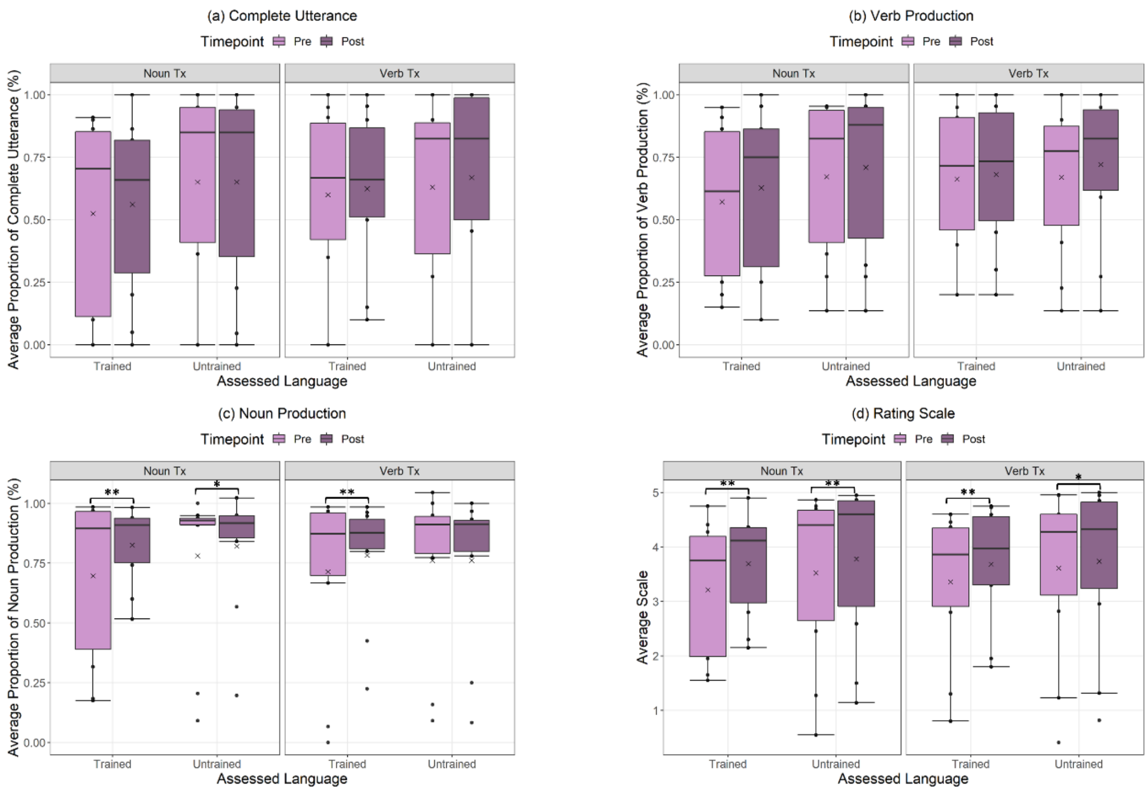


Figure 5.3. Group-level performance on sentence production before and after both noun and verb treatment. Boxplot capturing the average performance in the trained and untrained languages based on measures including: (a) average proportion of complete utterance (CU, 1.00 = 100%), (b) average proportion of accurate verb production (1.00 = 100%), (c) average proportion of noun production (1.00 = 100%), and (d) average rated scale between 0 – 5. Cross (×) indicates the mean value across participants; Asterisk (*) indicates significant improvement from pre- to post-treatment based on pairwise comparisons: * $p < 0.05$, ** $p < 0.01$.

5.4.3 Generalization to discourse production

Inter-rater reliability measures showed significant correlations for all discourse measures in L1 and L2 (Table 5.5). Figures 5.4 illustrates group-level performance as measured by total numbers of narrative words (a), nouns (b), verbs (c), CUs (d), and utterances (e). Individual performance based on the same measures is shown in Appendix D Table 4. Mixed-model results revealed that the total number of narrative words improved significantly in both treated (β = 0.20, SE = 0.04, $p < 0.01$) and untreated (β = 0.23, SE =

0.04, $p < 0.01$) languages following noun treatment, and in the untreated language following verb treatment ($\beta = 0.16$, SE = 0.04, $p < 0.01$). The extent of this generalization in the treated language was significantly greater after noun treatment than verb treatment ($\beta = -0.13$, SE = 0.06, $p < 0.05$). Results also showed a significant gain of noun production in the untreated language following noun treatment ($\beta = 0.25$, SE = 0.08, $p < 0.01$). In addition, there was a significant improvement of verb production in both treated ($\beta = 0.19$, SE = 0.09, $p < 0.05$) and untreated ($\beta = 0.17$, SE = 0.09, $p < 0.05$) languages following noun therapy. Results from the model predicting CUs further captured a significant improvement in both treated ($\beta = 0.30$, SE = 0.12, $p < 0.05$) and untreated ($\beta = 0.25$, SE = 0.12, $p < 0.05$) languages after noun treatment. Since generalization patterns were mostly observed in noun treatment, post-hoc analyses were conducted to examine whether performance in verb treatment differed by training in L1 (Mandarin) versus L2 (English). Results showed that when training verbs in L1, the number of narrative words improved significantly in both treated ($\beta = 0.22$, SE = 0.07, $p < 0.05$) and untreated ($\beta = 0.24$, SE = 0.07, $p < 0.01$) languages, and the number of nouns also improved in the treated language ($\beta = 0.39$, SE = 0.15, $p < 0.05$). When training verbs in L2, the number of narrative words improved significantly in the untreated language ($\beta = 0.13$, SE = 0.05, $p < 0.05$). These results indicated that targeting semantic representations of nouns and verbs during treatment facilitated generalization beyond the single-word level. However, patterns of generalization may differ by the target grammatical category. Training nouns led to better overall lexical retrieval and more complete utterances in both treated and untreated languages. In contrast, generalization in verb treatment was mostly constrained to general lexical retrieval, particularly when treatment targeted L1.

Table 5.5. Inter-rater reliability measures (Pearson's r) of discourse production.

	Total # of CU	Total # of Narrative Words	Total # of Utterances	Total # of Nouns	Total # of Verbs
L1	0.91**	0.97**	0.86**	0.94**	0.91**
L2	0.94**	0.97**	0.89**	0.95**	0.96**

CU: complete utterance; L1: Mandarin, L2: English; **: *p*-value < 0.01.

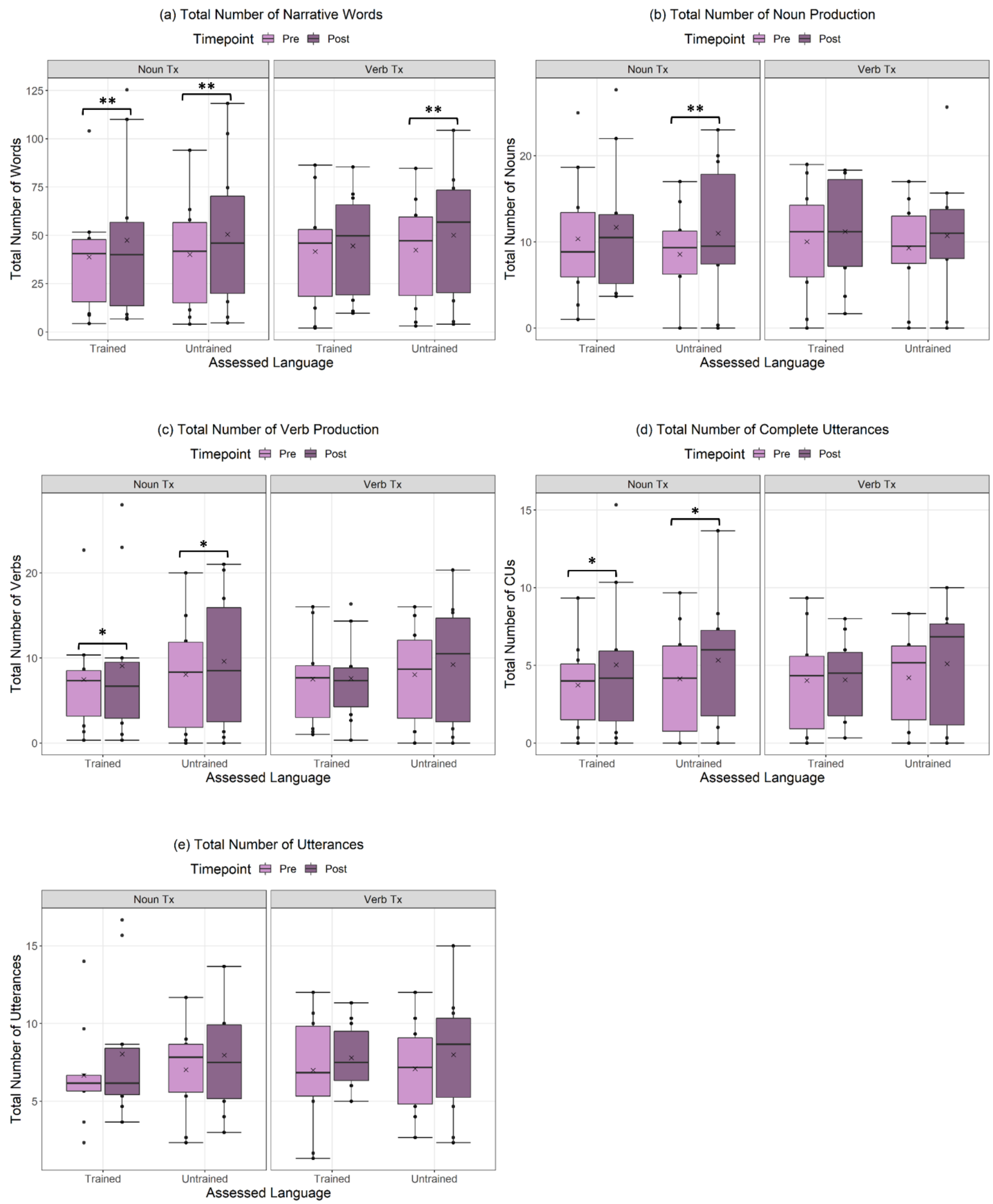


Figure 5.4. Group-level performance on discourse tasks before and after both noun and verb treatment. Boxplots showing scores averaged across three discourse tasks as measured by the total number of (a) narrative words, (b) nouns, (c) verbs, (d) CUs, and (e) utterances. Cross (×) indicates the mean value across participants; Asterisk (*) indicates significant improvement from pre- to post-treatment based on pairwise comparisons: * $p < 0.05$, ** $p < 0.01$.

5.4.4 Generalization to untrained verbs and nouns

Individual performance on untrained naming tasks in each treatment cycle is shown in Appendix Table 5. Group-level performance is illustrated in Figure 5.5. Results from the model predicting the naming accuracy of untrained nouns (i.e., BNT, NNB) showed a significant improvement in the treated language following noun treatment ($\beta = 0.47$, SE = 0.19, $p < 0.05$) but not verb treatment ($p > 0.05$). Results did not show significant changes in the untreated language after either noun or verb treatment (p-values > 0.05). Results from the models predicting naming accuracy of untrained verbs (i.e., NNB, VNT) revealed a significant improvement in the treated language after both noun ($\beta = 0.68$, SE = 0.23, $p < 0.01$) and verb treatment ($\beta = 0.63$, SE = 0.25, $p < 0.05$). Noun treatment also showed a significant generalization to untrained verbs in the untreated language ($\beta = 0.76$, SE = 0.28, $p < 0.01$), and this magnitude of change was significantly larger than verb treatment ($\beta = -0.80$, SE = 0.40, $p < 0.05$). Follow-up analyses were conducted to examine if these generalization patterns differed by the treatment language (i.e., L1 vs. L2). Findings showed that training nouns in L2 (English) promoted accurate naming of untrained verbs in the treated language, i.e., English ($p < 0.05$). In contrast, training nouns in L1 (Mandarin) facilitated accurate naming of untrained verbs in the untreated language, i.e., English ($p < 0.05$). These results indicated that both noun and verb treatment facilitated accurate naming of untrained items. However, noun treatment promoted better naming of untrained verbs to a significantly greater extent than verb treatment.

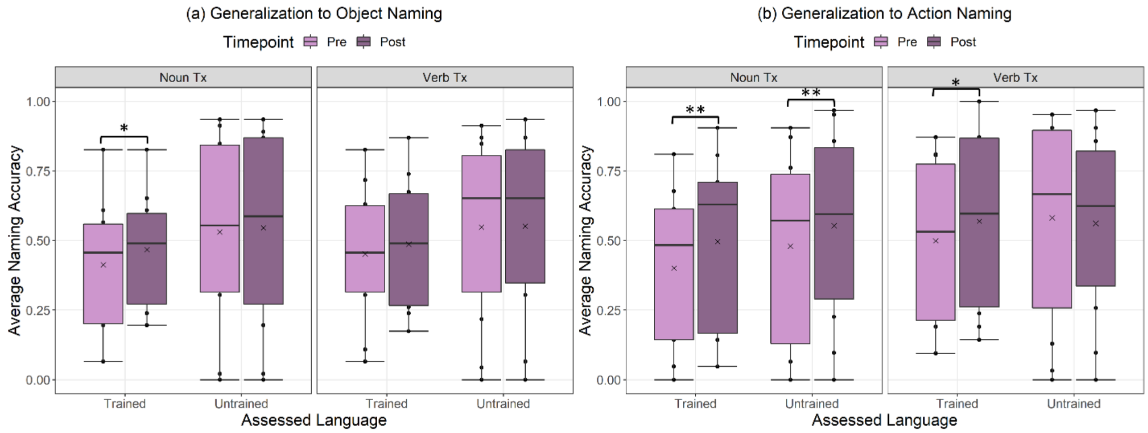


Figure 5.5. Group-level performance on (a) object naming and (b) action naming. Scores from the BNT and NNB were used to capture object naming (n = 46 per language); scores from the NNB and VNT of the NAVS were used to measure action naming (n = 21 for Mandarin, n = 31 for English). Y-axis: naming accuracy averaged across participants. Cross (×) indicates the mean value across participants; Asterisk (*) indicates significant improvement from pre- to post-treatment based on pairwise comparisons: * $p < 0.05$, ** $p < 0.01$.

5.5 Discussion

The current study aimed to investigate patterns of treatment-induced language recovery between nouns and verbs via the implementation of the same treatment steps for both noun and verb treatment. Specifically, we examined to what extent differences in the following three measures emerge between training nouns and verbs: (1) *treatment acquisition, within-language, and cross-language generalizations*, (2) *generalizations to sentence and discourse production*, and (3) *generalizations to untrained naming*.

This study captured seven key findings, as highlighted below (summarized in Table 5.6). In general, Mandarin-English BWA showed significant improvement on the overall aphasia severity and lexical retrieval, as evidence by changes on the WAB-AQ in the treated language (i.e., L1) following noun treatment in L1, and on the BNT in the treated language (i.e., L2) after verb treatment in L2 (Key Finding 1). During treatment, our participants showed a positive treatment gain in both noun and verb treatment, as evidenced by a significant improvement in naming the trained items over time. The magnitude of this direct treatment effect was significantly larger when training verbs than nouns (Key Finding 2). In addition, generalization to semantically-related items was found in noun treatment, but the extent was not significantly greater than in verb treatment (Key Finding 3). Items in the untreated language also improved significantly over time in both noun and verb treatment, but to a significantly greater extent in verb treatment (Key Finding 4). These findings suggest a robust treatment gain in both noun and verb treatment, but the magnitude of change was greater in verb treatment. Additionally, within-language generalization was captured in noun treatment, and cross-language generalization was observed for both treatment with a larger magnitude for verb treatment.

Mandarin-English BWA further demonstrated generalizations to sentence production following both noun and verb treatment, as reflected by significant gains in verb argument production and the overall accuracy of utterances. These generalizations did not differ between training nouns and verbs (Key Finding 5). Moreover, results from discourse analysis captured more generalizations after noun treatment than verb treatment (Key Finding 6). Specifically, training nouns facilitated generalizations to the amount of lexical retrieval and CUs in both treated and untreated languages, whereas training verbs mainly generalized to lexical retrieval when treatment targeted L1 (Mandarin). Finally, our participants exhibited significant improvement in naming untrained nouns following noun treatment and naming untrained verbs after verb treatment. Noun treatment additionally promoted greater generalization to untrained verbs as compared to verb treatment (Key

Finding 7). This pattern of generalization further varied by the treatment language as improvement in the untrained verbs was found in the treated language (i.e., L2) when noun treatment targeted L2, and in the untreated language (i.e., L2) when noun treatment targeted L1. This study, to our knowledge, is the first one in bilingual aphasia rehabilitation that included the largest sample size of Mandarin-English BWA. Findings from this study provide evidence of treatment-induced language recovery targeting different grammatical categories and help grow the evidence base for aphasia rehabilitation in Mandarin-English BWA. In the discussion that follows, we elaborate on these findings.

Table 5.6. Summary of key findings.

	Noun treatment	**Verb treatment**
1. Improvement on standardized assessments	✓	✓
Note:	WAB-AQ in L1 (tx lang = L1)	BNT in L2 (tx lang = L2)
2. Direct treatment gain	✓	✓✓
3. Within-language generalization	✓	-
4. Cross-language generalization	✓	✓✓
5. Generalization to sentences	✓	✓
Note:	Lexical retrieval, overall accuracy	Lexical retrieval, overall accuracy
6. Generalization to discourse	✓✓	✓
Note:	Lexical retrieval, CUs	Lexical retrieval
7. Generalization to untrained naming	✓✓	✓
Note:	Untrained nouns, Untrained verbs in L2 (tx lang = L1 and L2)	Untrained verbs

Note: checkmark indicates a significant treatment or generalization effect, two checkmarks indicate a larger treatment or generalization effect; minus sign indicates no significant effect. L1: Mandarin, L2: English; WAB-AQ: Western Aphasia Battery Aphasia Quotient; BNT: Boston Naming Test; tx lang: treatment language; CUs: complete utterances.

Standardized language assessments

According to the established clinical benchmarks of aphasia recovery (Gilmore et al., 2019), our participants demonstrated significant improvement on the standardized language assessments, as evidenced by gains on the WAB-AQ in the treated language following noun treatment in L1, i.e., Mandarin, and on the BNT in the treated language following verb treatment in L2, i.e., English. Consistent with previous studies in bilingual aphasia treatment (Edmonds & Kiran, 2006; Kiran & Roberts, 2010; Li et al., 2020), these findings suggest that practicing lexical retrieval and associated features of an item facilitated the overall aphasia severity and better lexical retrieval ability. Although other scores did not exceed the benchmark, patterns of improvement were still observed in verb and noun naming (i.e., BNT, NNB, VNT), sentence production (i.e., ASPT), and semantic processing (i.e., PPT). These findings corroborate the robust effect of treatment approaches targeting the lexical-semantic processing in Mandarin-English BWA.

Treatment gain, within- and cross-language generalization

In accordance with previous studies in bilingual aphasia rehabilitation (Abutalebi et al., 2009; Faroqi-Shah et al., 2010; Gil & Goral, 2004; Kiran et al., 2013; Lerman et al., 2019; Li et al., 2020; Meinzer et al., 2007; Peñaloza et al., 2020), the current study replicated a significant direct treatment effect in both noun and verb treatment in Mandarin-English BWA. Our findings support the hypothesis that repeated activation of labels and their semantic features strengthens the links between semantic representations and associated lexical representations, leading to increased lexical-retrieval accuracy (Boyle & Coelho, 1995; Boyle, 2004; Coelho et al., 2000). Yet, most previous studies have only included individuals speaking Indo-European languages. Our findings suggest that despite the different linguistic structures in Mandarin Chinese, training in either L1 or L2 facilitates the direct treatment effect in individuals speaking typologically different languages, i.e., Mandarin-English.

Evidence of bilingual aphasia rehabilitation has been mostly derived from treatment for nouns (Edmonds & Kiran, 2006; Kiran et al., 2013; Kiran & Iakupova, 2011; Kiran & Roberts, 2010). The current study successfully adapted semantic-based treatment targeting verbs, indicating that strengthening the lexical-semantic links promotes treatment gains regardless of the grammatical category. Our results further identified a more significant treatment gain when training verbs versus nouns. Previous studies have suggested that retrieving nouns associated with the thematic roles of a verb facilitates increased verb retrieval (Edmonds et al., 2009; Li et al., 2020; McRae et al., 2005; Wambaugh & Ferguson, 2007). Hence, specific feature categories in verb treatment, such as *subject* and *object*, might have primed verb retrieval. Future studies should examine the specific treatment ingredients that drive the differences between training nouns and verbs. Our findings showed promising rehabilitation outcomes using semantic-based treatment targeting nouns and verbs in Mandarin-English BWA.

Mandarin-English BWA also demonstrated significant improvement in semantically-related items, but only in noun treatment. This finding is consistent with previous studies that also found this pattern of generalization when therapy targeted nouns (Kiran et al., 2013; Kiran & Iakupova, 2011; Kiran & Roberts, 2010), and supports the hypothesis that targeting the semantic system spreads activation to words that share semantic features (Boyle & Coelho, 1995; Boyle, 2004; Coelho et al., 2000). Nevertheless, our results did not capture any within-language generalization in verb treatment (Wambaugh et al., 2014; Wambaugh & Ferguson, 2007). One explanation of this null finding is the degree of semantic relatedness of the verb stimuli, which can be characterized based on various conceptual factors. For example, evidence from previous research has suggested that somatotopic information (i.e., body part) is automatically activated in verb processing and primes verbs sharing the same features (i.e., *licking* → *kissing*; Faroqi-Shah et al., 2009). Another factor that impacts the semantic relatedness of verbs is instrumentality (i.e., verbs involve an artificial instrument, such as *sweep*). Studies have found higher naming accuracy for instrumental versus non-instrumental verbs in individuals with aphasia (Bastiaanse & Jonkers, 1998; Jonkers & Bastiaanse, 2006; Kambanaros, 2009). Although each pair of stimuli was carefully paired in the current study, the aforementioned conceptual factors were not controlled across all stimuli and could differentially affect the degree of within-language generalization. Another explanation of a lack of generalization is the extent to which features are verb-specific (Faroqi-Shah et al., 2009). Previous studies have shown that training general semantic features (e.g., *use tools*) for a word (e.g., *dig*) may be insufficient in facilitating retrieval of another tool-use verb (e.g., *scoop*). Therefore, generalization to semantically-related verbs may require verb-specific features that directly link to the corresponding action name.

Items in the untrained language improved significantly in both noun and verb treatment, suggesting the potential for cross-language generalization in Mandarin-English BWA. This finding supports prior studies that have also reported a cross-language generalization in BWA (Edmonds & Kiran, 2006; Goral et al., 2012; Kiran & Iakupova, 2011; Kiran & Roberts, 2010; Lerman et al., 2017; Li et al., 2020; Miertsch et al., 2009). As posited by theories of bilingual language processing, activation in the shared semantic system should flow to both L1 and L2 lexical representations (Costa et al., 2006; Hermans et al., 1998). Although these theories are mostly tested on nouns, our findings imply a shared representation system for the bilingual verb processing (Lerman et al., 2017; Li et al., 2020; Salamoura & Williams, 2007).

The pattern of cross-language generalization was even more robust when treatment targeted verbs than nouns, as evidenced by larger magnitudes of improvement in translations of both trained and untrained items. These different patterns of cross-language generalization between nouns and verbs can be attributed to varying degrees of cross-language inhibitory control (Kiran et al., 2013). When both lexical representations are activated in bilingual lexical processing, language selection is achieved by inhibiting lexical representations in the non-target language (*Inhibitory Control Model*; Green, 1998). Given that the magnitude to which semantics are shared between languages is higher for concrete versus abstract words (de Groot, 1992; Van Hell & de Groot, 1998), training nouns may yield more cross-linguistic interference than training verbs, leading to stronger between-language inhibitory control (Green, 1998). Another explanation for this finding is that verbs in Mandarin do not carry rich morphosyntactic strucutres, making it easier to access their phonological representations. Hence, one would assume greater cross-language generalization in individuals who received verb treatment in L2. Among the four participants who showed significant effect sizes in the untrained verbs, three were trained in L2 (English; P3, P6, and P9), suggesting that training verbs in L2 promoted greater cross-language generalization. However, more samples in each treatment group are needed to test this assumption. Altogether, these findings indicate that training semantic features of nouns and verbs promotes generalization to the untreated language, but mechanisms of this generalization may differ by the target grammatical category.

Generalization to sentence and discourse production

Generalizations beyond the single-word level were further observed in Mandarin-English BWA. Specifically, our participants demonstrated gains in verb argument production in both treated and untreated languages following noun treatment. After verb treatment, another significant improvement in verb argument production was found in the treated language. The overall accuracy of sentence production also significantly improved in both languages following noun and verb treatment, as captured by the rating scale.

These findings indicate that direct retrieval practice of nouns and verbs facilitates lexical retrieval of nouns associated with thematic roles (i.e., agent, patient) in a sentence (Lerman et al., 2017). As pointed out by previous research, processing verbs may prime or activate their thematic roles (Ferretti et al., 2001; McRae et al., 2005). Hence, training the target verb promotes activation of its thematic roles, leading to increased production of verb arguments. In addition, since a verb's argument structure is considered an integral part of the verb's semantic representation (Conroy et al., 2006; Druks, 2002; Webster & Whitworth, 2012), repeated feature analysis of a verb's subject and object may have strengthened its predicate argument structure and basic syntactic structure (Edmonds, 2016; Edmonds et al., 2014). This hypothesized mechanism of generalization further corroborates our findings of significant gains in the untreated language. Given that Mandarin and English share the same basic sentence structure, i.e., subject-verb-object (SVO), lexical selection of subjects and objects in the treated language could aid in mapping thematic roles onto syntactic structures in the untreated language. These results suggest that integrating lexical retrieval, semantics, and sentence production during treatment promotes potential generalization to sentences in Mandarin-English BWA.

Mandarin-English BWA further demonstrated varying generalization patterns in discourse production, as reflected by significant improvement in the numbers of narrative words, nouns, verbs, and CUs in treated and untreated languages. These findings partially mirror those in sentence production, in which generalization was mainly confined to measures reflecting direct lexical retrieval during treatment. Hence, some levels of sentence production abilities may be necessary for successful generalization to discourse (Wambaugh et al., 2014). Our results suggest that repeated practice of a target word and its semantic features facilitates the overall lexical-retrieval ability even in linguistically demanding contexts (Knoph et al., 2015, 2017; Wambaugh et al., 2014).

Despite significant gains in varying discourse measures, patterns of generalization differed between training nouns and verbs. Most of the above measures improved significantly in both treated and untreated languages when training nouns. This finding is promising because it corroborates the robust effect of semantic-based intervention on the overall lexical retrieval (i.e., numbers of words) and sentence production (i.e., CUs). In contrast, generalization in verb treatment is mainly confined to general measures of lexical retrieval. This finding is consistent with previous studies implementing SFA targeting verbs in both monolinguals (Wambaugh et al., 2014) and multilinguals with aphasia (Knoph et al., 2015, 2017), which have reported gains in the number of words. Post-hoc analyses further showed that training verbs in L1 (Mandarin) promoted lexical retrieval in discourse to a larger extent than training verbs in L2 (English). Previous research has suggested that training in the dominant language facilitates treatment effect in BWA (Croft et al., 2011; Gil & Goral, 2004). Our participants reported a higher language ability rating for L1 (98.2) than L2 (82.4) based on the LUQ (Table 5.1), indicating that language proficiency plays a role in generalization to discourse production.

Surprisingly, our results did not reveal any significant change in CUs after verb treatment. Improvement in CUs has been previously reported in studies using sentence-based treatment, i.e., VNeST (Edmonds et al., 2009). This type of treatment focuses on verb retrieval in a sentence context, which leads to increased production of complete utterances. Although SFA includes feature categories of a verb's thematic roles, most treatment ingredients are constrained to the single-word level. Hence, the lack of a significant improvement in CUs after verb treatment suggests the need to integrate verbs in a sentence context during treatment to promote generalization to discourse. The mixed results above reflect diverse generalization mechanisms beyond the single-word level and suggest that these effects may differ by the trained grammatical category.

Generalization to untrained object and action naming

Finally, our participants exhibited widespread generalization to untrained naming tasks, as evidenced by significant improvement in naming the untrained objects and actions. Concretely, noun treatment facilitated generalization to object naming and verb treatment aided in action naming, both in the treated language. These findings align with previous treatment studies that reported gains in the treated language as measured by single-naming tasks (Lerman et al., 2017; Li et al., 2020). These results support the hypothesis that strengthening semantic knowledge not only spreads activation to the target and semantically-related words, but also leads to better overall lexical retrieval.

Training verbs did not generalize to object naming, which seems contradictory to the previous finding of a generalization from verb treatment to noun production in sentence tasks. Hence, this type of generalization may be specific to a sentence context that includes a verb and its semantic constraints, i.e., thematic roles assigned to argument structures. According to previous research, verb processing activates knowledge of the event that it denotes, which drives the priming of the nouns associated with thematic roles (Altmann & Kamide, 1999). In comparison to sentence production, object naming does not denote events, and hence training verbs might not have generated activation to untrained nouns in our study. Another account for the lack of generalization is that argument structures of the trained verbs may not be semantically related to items on the naming tasks (i.e., BNT, NNB). Thematic roles assigned to a target verb can be restricted to specific semantic categories, given that verbs are a powerful source of semantic constraint (McRae et al., 2015). For instance, potential objects of the verb *grind* typically include items with a hard surface (e.g., coffee beans, stones). Hence, the high semantic constraints imposed by a verb might have impeded generalization from verb treatment to naming untrained objects. Future studies should examine this tentative account by controlling for the semantic relatedness between treatment stimuli and naming task items.

We further observed significant generalizations from noun treatment to action naming in both treated and untreated languages, which again contradicted our hypothesis. From a semantic perspective, although the event encoded through a verb is essential in spreading activation to its associated knowledge, other components such as location, time, function, and participants can also activate an event (Lancaster & Barsalou, 1997). Hence, training feature categories of an object (i.e., function, characteristics, physical attributes, category, location) might have indirectly strengthened their connections to verbs in untrained naming tasks. In comparison to verbs, nouns are less semantically constrained and can prime verb processing (McRae et al., 2005). Given that our noun treatment stimuli included a variety of semantic categories (e.g., birds, clothing, furniture, etc.), it is possible that training these items triggered different events denoted by verbs and led to improved retrieval of untrained verbs. Another mechanism of this generalization can be attributed to the syntactic differences between L1 (Mandarin) and L2 (English). Although both languages share the same basic SVO structure, Mandarin is considered a pro-drop language as it allows the sentential subject to be omitted in specific contexts (Huang, 1989). For instance, a sentence such as "吃过了 [chi-guo-le]," meaning "I ate already," is grammatically correct even though no explicit subject "我 [wo]" is included. Therefore, verbs in Mandarin are in a more salient position as compared to verbs in English. This verb-saliency may further promote the activation of verbs from training nouns, especially when noun stimuli are an integral part of the verb's semantic representation (Conroy et al., 2006; Druks, 2002; Webster & Whitworth, 2012).

Interestingly, our post-hoc analyses showed that training nouns in L2 facilitated generalization to action naming in the treated language, whereas training nouns in L1 led to generalization to action naming in the untreated language. Here we propose two mechanisms of inhibitory control to account for this finding: the within-language semantic control (Belke et al., 2005; Kiran et al., 2013) and bilingual inhibition control (Green, 1998). There may be some degrees of semantic interference between nouns and verbs, given that nouns are part of a verb's semantic representation (Webster & Whitworth, 2012). In general, positive generalization in treatment occurs when increased activation due to therapy effects exceeds the interference of items during lexical selection (Kiran et al., 2013). In bilingual language processing, there has been abundant evidence suggesting a stronger inhibitory control in the dominant language (i.e., L1) when the target language is in the less dominant language (Linck et al., 2009; Meuter & Allport, 1999). Hence, when our participants were trained for nouns in L2 (English), the between-language inhibitory control may be stronger than the generalized activation from nouns to verbs, resulting in increased action naming in the same language. In those participants trained for nouns in L1, it appears that the within-language semantic interference between nouns and verbs may be stronger than between-language inhibitory control, hence precludes generalization to verb retrieval in the treated language. Future research should examine the effect of both semantic inhibition and bilingual inhibitory control on treatment generalizations. Altogether, our findings revealed that both noun and verb treatment promoted generalizations to untrained items, but noun treatment facilitated greater generalization to untrained verbs as compared to verb treatment. These findings suggested that training semantic representations of nouns and verbs leads to better overall naming ability. However, patterns of generalization vary between training nouns and verbs, which may depend on factors including the semantic constraints of each grammatical category, language-specific properties, and bilingual inhibitory control.

5.6 Limitations and future implications

Although the findings discussed above point to an overall robust treatment and generalization effect for both noun and verb treatment in Mandarin-English BWA, there are several limitations in this study. First, verb treatment did not show any generalization to semantically-related items, possibly due to factors affecting the semantic relatedness across treatment stimuli. Future studies should control for factors such as instrumentality (e.g., tool verbs) and somatotopic information (e.g., hand vs. leg actions) when selecting treatment stimuli. In addition, verb features in our study were selected from a previous database (Buchanan et al., 2019). These features may be too general to promote generalization to specific verbs. Hence, future studies should balance out general and specific features across items and investigate the effect of each type of features on within-language generalization. Another potential direction is to examine the active ingredients that may drive the differences in treatment effects between training nouns and verbs (Boyle et al., 2022). Furthermore, while widespread generalizations beyond the trained items were evident in standardized language tasks, patterns varied between training nouns and verbs. Future research should examine the effect of potential factors on treatment generalizations, including semantic constraints elicited by stimuli, linguistic differences between L1 and L2, and bilingual language control.

5.7 Conclusion

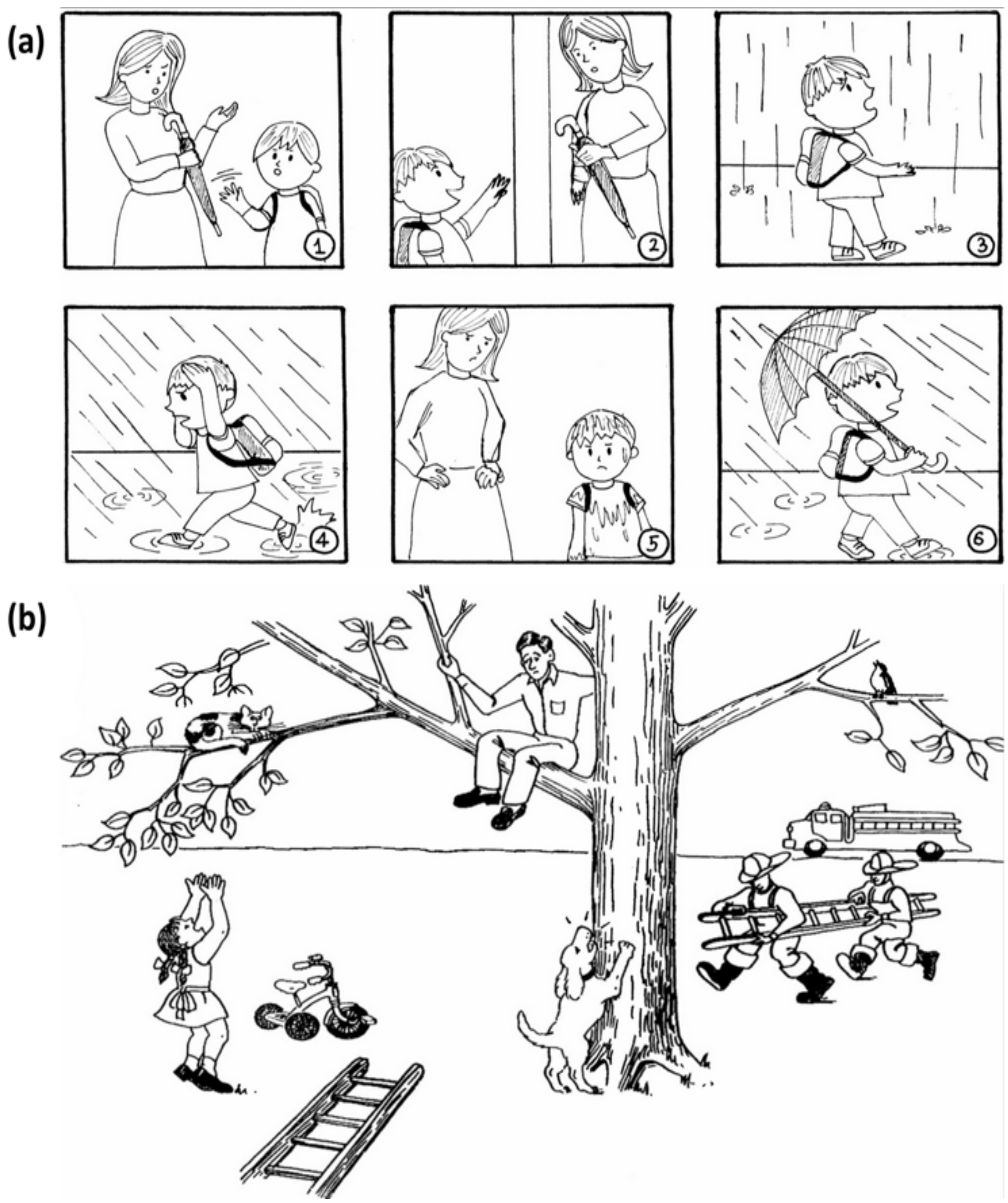
The current study aimed to investigate treatment-induced patterns of language recovery between nouns and verbs. A group of twelve Mandarin-English BWA received semantic-based treatment targeting nouns and/or verbs. Performance on the standardized language assessments demonstrated a significant gain in the overall aphasia severity (i.e., WAB-AQ) following noun treatment and another significant gain in lexical retrieval ability (i.e., BNT) following verb treatment, both in the treated language. Treatment gains, within-language, and cross-language generalizations were captured via weekly naming probes in both Mandarin and English. Our results showed a direct treatment gain in both noun and verb treatment, but to a significantly larger extent in verb treatment. Generalization to semantically-related untrained items was identified in noun but not verb treatment. Cross-language generalizations were observed in both treatments but significantly greater when training verbs than nouns. These findings support a strong effect of semantic-based treatment targeting both nouns and verbs in Mandarin-English BWA. However, patterns of treatment and generalization effects varied by the target grammatical category.

Widespread generalizations beyond the single-word level and to untrained naming tasks were also evident in our participants. Performance in sentence production indicated significant improvements in lexical retrieval of thematic roles and the overall accuracy of sentences following both noun and verb treatment. In discourse tasks, generalizations to the overall lexical retrieval and complete utterances were found after noun treatment in both treated and untreated languages, whereas generalization was mainly confined to lexical retrieval following verb treatment, particularly when treatment targeted L1. Finally, our participants showed generalizations to untrained naming tasks following both noun and verb treatment, with greater generalization to untrained verbs following noun treatment. In sum, these findings support the effectiveness of semantic-based treatment targeting both nouns and verbs in Mandarin-English BWA. Patterns of generalizations within and beyond treatment differed by the target grammatical category and may depend on a combination of stimuli- and language-specific factors. This study provides evidence of treatment-induced language recovery targeting different grammatical categories and grows the evidence base for aphasia rehabilitation in Mandarin-English BWA.

5.8 Appendix

APPENDIX A. STIMULI

Appendix A Figure 1. Picture stimuli for the discourse tasks. (a) *Umbrella* (sequential-picture), (b) *Cat Rescue* (single-picture).



Appendix A Table 1. Sample stimuli for verbs and nouns.

ESN1	MSN1	ESN2	MSN2	ESN3	MSN3
shark	鲨鱼	whale	鲸鱼	raft	筏
peach	桃子	apricot	杏子	smoke	烟
shirt	衬衫	coat	大衣	fence	栅栏
garlic	大蒜	pepper	辣椒	dentist	牙医
duck	鸭子	goose	鹅	barrel	桶
ESV1	**MSV1**	**ESV2**	**MSV2**	**ESV3**	**MSV3**
throw	扔	catch	接	pinch	捏
cry	哭	laugh	大笑	mix	搅拌
drink	喝	eat	吃	pray	祈祷
measure	量	weigh	称	read	读
walk	走	run	跑	wash	洗

Note: ESN1 – ESN3: English nouns set 1 (trained stimuli), set 2 (semantically-related items), set 3 (control items); MSN1 – MSN3: Mandarin nouns sets 1 – 3; ESV1 – ESV3: English verbs sets 1 – 3; MSV1 – MSV3: Mandarin verbs sets 1 – 3. Set 1 stimuli were used for treatment, depending on the language assigned for each participant.

Appendix A Table 2. Semantic features and their labels for the word *"mussel"*.

Features	Y/N	Feature Category
alive	Y	characteristics
can be eaten raw	Y	characteristics
can tie	N	
comes from chickens	N	
found in or near water	Y	characteristics/location
found on trees	N	
ground-dwelling	N	
hard	Y	physical attributes/characteristics
has a shell	Y	physical attributes/characteristics
has a tail	N	
has four legs	N	
is a fruit	N	
is a machine	N	
is an animal	Y	category
is food	Y	category
is fuzzy	N	
lightweight	Y	physical attributes/characteristics
made of wool	N	
slimy	Y	physical attributes/characteristics
small	Y	physical attributes/characteristics

Note: Original features were extracted from Sandberg et al. (2020). The first column includes a list of validated features for the target word; the second column indicates if a feature applies to the target word or not (Y = Yes; N = No). The third column includes the assigned feature categories based on the noun SFA treatment protocol.

Appendix A Table 3. Modified semantic features and their labels for the word *"nodding"*.

Features	Y/N	Feature Category
for styling	N	
in a business meeting	Y	location
in the study room	N	
is harmful	N	
is intentional	Y	physical attributes
is loud	N	
is painful	N	
is skillful	N	
move up and down	Y	physical attributes
moving quickly	Y	physical attributes
the head	Y	object
the president	Y	subject
to communicate	Y	purpose
to cook	N	
to express attitudes	Y	purpose
to greet	Y	purpose
to send a signal	Y	purpose
to show agreement	Y	purpose
to show disagreement	N	
to show understanding	Y	purpose
to teach students	N	
use hands	N	
use the mouth	N	
with a stick	N	

Note: Original features were extracted from Buchanan et al. (2019) and modified with descriptive phrases (e.g., "to…", "in…"). The first column includes a list of validated features for the target word; the second column indicates whether a feature applies to the target word or not (Y = Yes; N = No). The third column includes the assigned feature categories based on the verb SFA treatment protocol.

APPENDIX B. VERBAL INSTRUCTIONS FOR NAMING SCREENER AND PROBES

English: "Please name the following object/action in English."

Mandarin: "请用中文命名下列物体/动作."

Prompts were not provided unless patient responded: (1) the name of a whole object instead of the specific part (e.g., target word: "*flipper*", response: "*dolphin*"), (2) the name of a specific part instead of the whole target (e.g., target word: "*drink*", response: "*glass*"), (3) a supraordinate response (e.g., target word: "*eagle*", response: "*bird*").

APPENDIX C. TREATMENT STEPS FOR NOUNS (A) AND VERBS (B)

(a) Noun treatment

Step 1. Spontaneous Naming: a picture of the target noun (e.g., "*scarf"*) was presented in the center of the screen. Patient was asked to name the picture followed by clinician's feedback regardless of the accuracy.

Step 2. Feature Category Assignment: fifteen features of the target item were randomly presented across sessions. First, patient was instructed to select features that did not apply to the target. These features were dragged into the first box (i.e., Feature does not match item) followed by clinician's feedback. Then, patient was directed to assign the applied features to their corresponding feature categories: (1) function (used for), (2) characteristics (it has/is), (3) physical attributes (made of/appears), (4) category (belongs to), and (5) location (it is found/located). Feedback was again provided. Features were built in audio sound for individuals with reading difficulties using *SpeechSynthesis*.

Step 3. Association: patient was asked to produce features or items associated with the target word. Feedback was provided if response was incorrect or no response: "try to think of a personal object, a person, an experience that has something in common with the target."

Step 4. Feature Verification: patient verified whether the same features from Step 2, presented in a different order, applied to the target by answering yes/no questions. Visual feedback was provided.

Step 5. Picture Naming: patient was asked to name the same picture followed by clinician's feedback.

Step 6. Sentence Formulation: patient was asked to create a sentence with the target word followed by clinician's feedback on grammaticality and semantics.

(b) Verb treatment

Step 1. Spontaneous Naming: a picture of the target verb (e.g., "*dive"*) was presented in the center of the screen. Patient was asked to name the picture followed by clinician's feedback regardless of the accuracy.

Step 2. Feature Category Assignment: fifteen features of the target item were randomly presented across sessions. First, patient was instructed to select features that did not apply to the target. These features were dragged into the first box (i.e., Feature does not match item) followed by clinician's feedback. Second, patient was directed to assign the applied features to their corresponding feature categories: (1) subject (who does this), (2) purpose/object (why is this done), (3) physical attributes (appears), (4) how (which body part/tool is used), and (5) location (it is found/located). Feedback was again provided. Features were built in audio sound for individuals with reading difficulties using *SpeechSynthesis*.

Step 3. Association: patient was asked to produce features or actions associated with the target word. Feedback was provided if response was incorrect or no response: "try to think of a personal object, a person, an experience that has something in common with the target."

Step 4. Feature Verification: patient verified whether the same features from Step 2, presented in a different order, applied to the target by answering yes/no questions. Visual feedback was provided.

Step 5. Picture Naming: patient was asked to name the same picture followed by clinician's feedback.

Step 6. Sentence Formulation: patient was asked to create a sentence with the target word followed by clinician's feedback on grammaticality and semantics.

Appendix D. Individual Assessment and Treatment Outcomes

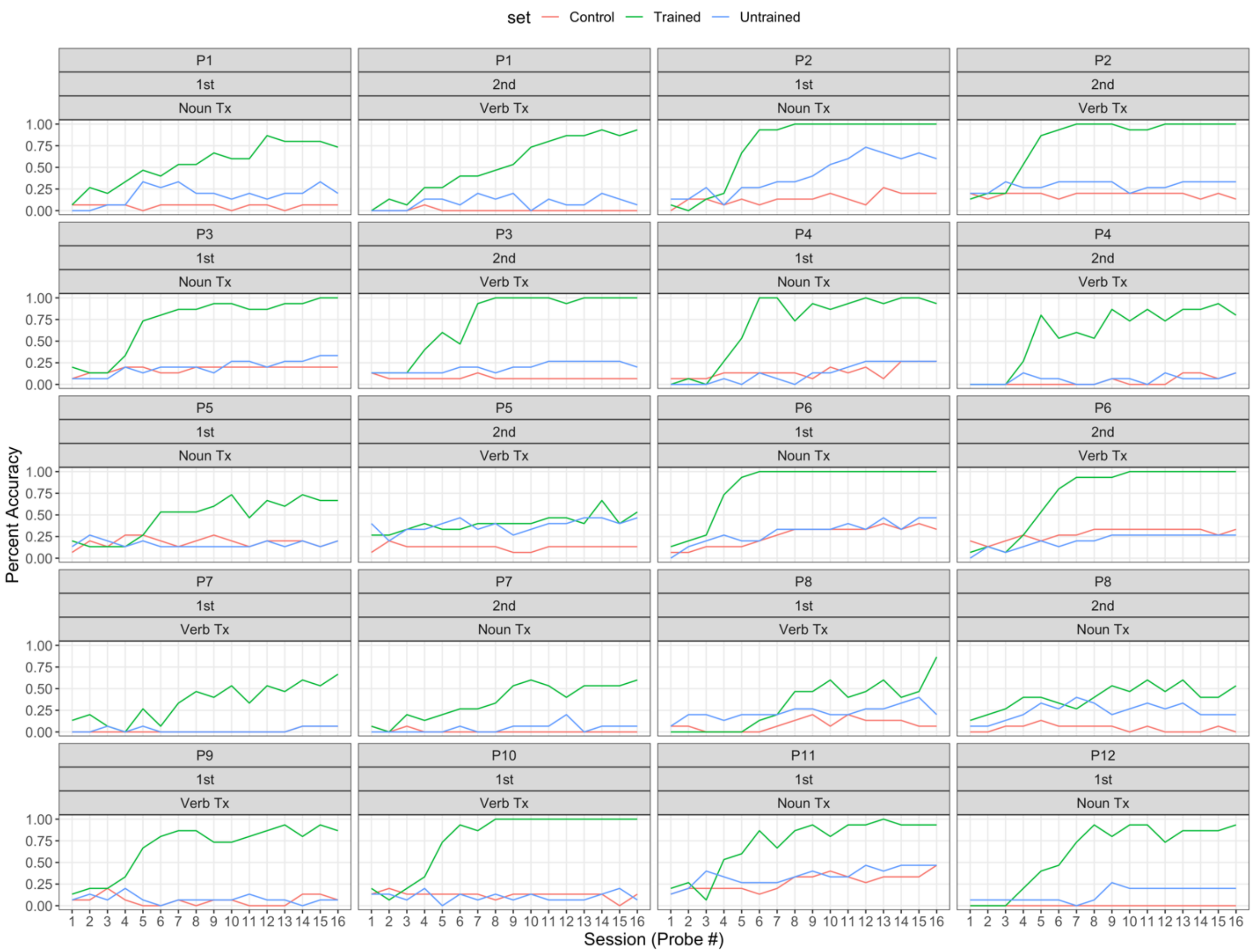
Appendix D Table 1. Individual performance on standardized assessments before and after each treatment cycle.

ID	Tx L	Tx	Time-point	WAB-AQ		BNT %		NNB obj %		NNB act %		VNT %		ASPT ALL %		CLQT EF-NV	PPT %
				L2	L1	L2	L1	L2	L1	L2	L1	L2	L1	L2	L1		
P1	L1	1N	pre	47.6	34.1	18.3	3.3	62.5	12.5	6.3	0.0	13.6	0.0	25.0	10.0	23.0	76.6
			post	52.3	45.1	6.7	10.0	50.0	50.0	25.0	6.3	27.3	5.0	18.8	10.0	16.0	79.7
		2V	pre	55.5	48.8	16.7	23.3	37.5	43.8	18.8	12.5	9.1	10.0	31.3	35.0	27.0	82.8
			post	56.3	48.0	23.3	10.0	56.3	56.3	25.0	31.3	31.8	20.0	56.3	45.0	25.0	89.1
P2	L1	1N	pre	92.3	86.9	80.0	73.3	100.0	100.0	87.5	87.5	86.4	80.0	96.9	90.0	17.0	96.9
			post	93.8	92.1	81.7	73.3	100.0	100.0	93.8	87.5	100.0	90.0	96.9	95.0	20.0	93.8
		2V	pre	96.8	88.3	80.0	73.3	100.0	100.0	87.5	87.5	90.9	80.0	100.0	80.0	20.0	100.0
			post	94.8	89.6	83.3	83.3	100.0	93.8	93.8	93.8	95.5	85.0	96.9	90.0	21.0	100.0
P3	L2	1N	pre	78.7	86.5	38.3	86.7	93.8	100.0	62.5	81.3	72.7	80.0	84.4	75.0	31.0	95.3
			post	79.6	87.9	45.0	83.3	93.8	100.0	87.5	93.8	81.8	85.0	68.8	90.0	29.0	96.9
		2V	pre	89.7	87.8	48.3	86.7	93.8	100.0	81.3	100.0	81.8	95.0	90.6	85.0	30.0	95.3
			post	84.6	88.6	51.7	90.0	87.5	100.0	87.5	87.5	86.4	85.0	75.0	100.0	28.0	96.9
P4	L1	1N	pre	68.6	51.2	26.7	16.7	81.3	25.0	25.0	6.3	45.5	5.0	59.4	20.0	28.0	93.8
			post	71.3	65.7	33.3	20.0	87.5	68.8	43.8	18.8	59.1	15.0	75.0	70.0	17.5	96.9
		2V	pre	71.9	66.7	43.3	20.0	93.8	62.5	56.3	31.3	72.7	25.0	56.3	70.0	31.0	95.3
			post	74.3	64.7	33.3	20.0	87.5	43.8	62.5	37.5	68.2	35.0	53.1	60.0	30.0	96.9
P5	L2	1N	pre	82.9	77.7	46.7	53.3	75.0	87.5	81.3	68.8	45.5	65.0	90.6	75.0	7.0	84.4
			post	81.3	83.6	50.0	50.0	75.0	93.8	68.8	68.8	68.2	55.0	93.8	95.0	4.0	90.6
		2V	pre	80.4	83.8	48.3	46.7	81.3	93.8	75.0	62.5	59.1	65.0	96.9	80.0	7.0	92.2
			post	77.6	78.7	56.7	50.0	87.5	100.0	68.8	62.5	81.8	55.0	81.3	85.0	4.0	81.3
P6	L2	1N	pre	82.8	87.6	31.7	73.3	75.0	100.0	68.8	87.5	72.7	95.0	90.6	70.0	25.0	98.4

			post	78.8	91.3	38.3	83.3	81.3	93.8	68.8	93.8	72.7	95.0	78.1	85.0	27.0	96.9
		2V	pre	88.3	89.7	45.0	80.0	75.0	100.0	50.0	100.0	81.8	95.0	87.5	90.0	27.0	96.9
			post	87.1	92.0	48.3	80.0	75.0	100.0	81.3	100.0	86.4	90.0	87.5	90.0	28.0	95.3
P7	L1	1V	pre	39.2	51.9	3.3	13.3	6.3	6.3	6.3	25.0	0.0	15.0	0.0	0.0	18.0	60.9
			post	43.5	52.4	6.7	16.7	6.3	18.8	12.5	18.8	13.6	10.0	0.0	20.0	19.0	85.9
		2N	pre	39.3	52.7	3.3	20.0	0.0	25.0	6.3	18.8	9.1	10.0	0.0	5.0	18.0	81.3
			post	41.9	52.9	1.7	13.3	0.0	31.3	12.5	31.3	9.1	20.0	3.1	20.0	18.0	81.3
P8	L1	1V	pre	13.3	50.0	0.0	3.3	0.0	12.5	0.0	25.0	0.0	15.0	3.1	0.0	16.0	75.0
			post	16.0	53.6	0.0	16.7	0.0	37.5	0.0	25.0	0.0	15.0	0.0	10.0	13.0	73.4
		2N	pre	14.9	52.9	0.0	13.3	0.0	31.3	0.0	18.8	0.0	10.0	0.0	0.0	10.0	79.7
			post	14.9	53.9	0.0	16.7	6.3	37.5	0.0	18.8	0.0	10.0	18.8	15.0	16.0	73.4
P9	L2	1V	pre	69.0	78.4	23.3	63.3	75.0	75.0	50.0	81.3	40.9	65.0	71.9	80.0	25.0	96.9
			post	70.9	80.7	31.7	50.0	62.5	87.5	43.8	62.5	50.0	55.0	43.8	65.0	23.0	89.1
P10	L2	1V	pre	93.8	88.3	53.3	53.3	93.8	93.8	93.8	93.8	81.8	90.0	90.6	90.0	29.0	98.4
			post	95.6	87.3	60.0	56.7	100.0	93.8	100.0	81.3	100.0	70.0	93.8	95.0	26.0	100.0
P11	L2	1N	pre	77.7	78.4	30.0	26.7	62.5	50.0	37.5	43.8	45.5	55.0	68.8	90.0	27.0	98.4
			post	78.5	74.2	28.3	30.0	81.3	87.5	62.5	75.0	68.2	75.0	84.4	95.0	28.0	96.9
P12	L2	1N	pre	82.9	90.9	33.3	93.3	87.5	93.8	43.8	62.5	50.0	60.0	81.3	75.0	23.0	95.3
			post	80.5	93.5	31.7	90.0	87.5	100.0	56.3	68.8	50.0	60.0	78.1	85.0	23.0	93.8

Note: Tx L: treatment language, L2: English, L1: Mandarin; 1N: first treatment = noun, 2N: second treatment = noun, 1V: first treatment = verb, 2V: second treatment = verb; WAB-AQ: Western Aphasia Battery Aphasia Quotient (total = 100), its L1 equivalence was obtained via the Aphasia Battery in Chinese Aphasia Quotient (ABC; total = 100); BNT = Boston Naming Test (total = 60 for L2, total = 30 for L1); NNB obj: Northwestern Naming Battery Object Naming (total = 16 in L2 and L1); NNB act: Northwestern Naming Battery Action Naming (total = 16 in L2 and L1); VNT: Verb Naming Test (total = 22 in L2; total = 20 in L1); ASPT ALL: Argument Structure Production Test with all arguments (total = 32 in L2, total = 20 in L1); CLQT EF-NV: Cognitive Linguistic Quick Test Executive Function Non-verbal (total = 31); PPT: Pyramids and Palm Trees (total = 64).

(a) Individual Naming Accuracy in the Treated Language



Appendix D Figure 6. Individual mean accuracy on naming probes in the (a) treated and (b) untreated languages in each treatment cycle. X-axis is probe sessions 1 – 16: 1 – 3 (baseline phase), 4 – 13 (treatment phase), 14 – 16 (post-treatment phase). Y-axis is the average response accuracy (1.00 = 100 %). 1st: first treatment cycle, 2nd: second treatment cycle; Tx: treatment; Control_Tr: translations of control items, Trained_Tr: translations of trained items, Untrained_Tr: translations of semantically-related untrained items.

Appendix D Table 2. Individual effect sizes for each set of probe stimuli.

ID	Tx Lang	Tx	Control	Trained	Untrained	Control Tr	Trained Tr	Untrained Tr
P1	L1	1N	0.00	1.55	**1.49***	0.07	0.19	0.75
		2V	0.00	**3.35***	0.75	0.00	0.00	0.30
P2	L1	1N	0.39	**3.70****	1.15	-0.11	**1.24***	0.69
		2V	-0.06	2.13	0.20	-0.16	**1.96****	0.38
P3	L2	1N	0.28	2.24	0.97	0.62	0.64	0.27
		2V	-0.08	**2.52***	0.32	-0.11	**2.07****	0.38
P4	L1	1N	0.79	**6.41*****	**1.29***	0.28	0.61	0.32
		2V	N/A	N/A	N/A	0.44	1.11	0.18
P5	L2	1N	0.13	1.46	-0.05	0.35	0.30	0.30
		2V	0.00	0.53	0.28	0.00	0.16	0.18
P6	L2	1N	0.93	1.98	0.98	0.96	0.74	0.24
		2V	0.34	**3.17***	0.79	0.19	**1.39***	0.67
P7	L1	1V	0.25	1.36	0.30	N/A	N/A	N/A
		2N	-0.21	1.62	0.27	N/A	N/A	N/A
P8	L1	1V	0.21	2.23	0.42	N/A	N/A	N/A
		2N	0.00	0.60	0.39	N/A	N/A	N/A
P9	L2	V	0.00	1.78	-0.15	0.11	**1.48***	0.24
P10	L2	V	-0.18	**2.30***	0.07	-0.09	0.34	0.78
P11	L2	N	0.52	1.95	0.51	0.50	**1.23***	0.85
P12	L2	N	0.00	**4.98****	0.53	0.00	-0.06	0.10

Note: Tx Lang: treatment language, L2: English, L1: Mandarin; 1N: first treatment = noun, 2N: second treatment = noun, 1V: first treatment = verb, 2V: second treatment = verb; Control_Tr: translations of Set 3 (control items), Trained_Tr: translations of Set 1 (trained items), Untrained_Tr: translations of Set 2 (semantically-related items). Effect size for each stimuli set was calculated using the Cohen's *d* statistic (equation 5-2). When the pre-treatment SD was 0, the pooled SD from the other two sets of stimuli were calculated (equation 5-3); ES was unavailable (N/A) if the pre-treatment SD was 0 for all three sets of stimuli (i.e., Control, Trained, and Untrained). Benchmarks for the trained items: * 2.3 (small), ** 3.7 (medium), *** 5.5 (large); Benchmarks for the untrained items (i.e., Control, Control_Tr, Untrained, Untrained_Tr, Trained_Tr): * 1.2 (small), ** 1.7 (medium), *** 3.3 (large).

Appendix D Table 3. Individual performance on sentence production before and after each treatment cycle.

ID	Tx Lang	Tx	Time-point	CU %		Verb %		Noun %		Scale	
				T	U	T	U	T	U	T	U
P1	L1	1N	pre	10.0	36.4	25.0	36.4	31.7	90.9	1.6	2.5
			post	20.0	22.7	25.0	31.8	60.0	84.1	2.2	2.6
		2V	pre	35.0	27.3	40.0	40.9	66.7	77.3	2.8	2.8
			post	50.0	45.5	45.0	59.1	80.0	78.0	3.3	3.0
P2	L1	1N	pre	90.0	100.0	95.0	95.5	86.7	100.0	4.8	4.9
			post	100.0	90.9	100.0	95.5	98.3	102.3	4.9	4.9
		2V	pre	95.0	100.0	95.0	100.0	96.7	104.5	4.6	5.0
			post	90.0	100.0	85.0	100.0	85.8	100.0	4.8	5.0
P3	L2	1N	pre	86.4	100.0	90.9	95.0	95.5	91.7	4.4	4.6
			post	68.2	95.0	86.4	95.0	89.4	93.3	4.4	4.8
		2V	pre	81.8	90.0	90.9	90.0	95.5	90.0	3.8	4.6
			post	77.3	100.0	95.5	95.0	89.4	96.7	4.6	4.9
P4	L1	1N	pre	15.0	54.5	15.0	54.5	60.8	93.9	2.1	3.2
			post	55.0	72.7	50.0	90.9	78.3	90.2	3.5	3.9
		2V	pre	70.0	63.6	75.0	68.2	84.2	92.4	4.3	4.0
			post	55.0	63.6	65.0	90.9	84.2	85.6	3.9	4.1
P5	L2	1N	pre	90.9	75.0	81.8	80.0	97.0	92.5	4.0	4.2
			post	81.8	85.0	86.4	75.0	92.4	95.0	4.0	4.5
		2V	pre	63.6	85.0	68.2	80.0	79.5	84.2	3.9	4.5
			post	77.3	75.0	81.8	75.0	94.7	90.8	4.1	4.3
P6	L2	1N	pre	81.8	95.0	86.4	95.0	98.5	95.0	4.3	4.7
			post	81.8	100.0	86.4	100.0	93.2	95.0	4.4	5.0
		2V	pre	90.9	100.0	100.0	100.0	96.2	95.0	4.5	5.0
			post	95.5	100.0	95.5	100.0	96.2	91.7	4.5	5.0
P7	L1	1V	pre	0.0	0.0	20.0	22.7	0.0	9.1	0.8	1.2
			post	15.0	0.0	20.0	27.3	42.5	8.3	1.8	1.3
		2N	pre	10.0	0.0	20.0	27.3	17.5	9.1	1.7	1.3
			post	0.0	0.0	25.0	27.3	51.7	19.7	2.8	1.5
P8	L1	1V	pre	0.0	0.0	20.0	13.6	6.7	15.9	1.3	0.4
			post	10.0	0.0	30.0	13.6	22.5	25.0	2.0	0.8
		2N	pre	0.0	0.0	35.0	13.6	18.3	20.5	2.0	0.5
			post	5.0	4.5	10.0	13.6	74.2	56.8	2.3	1.1

P9	L2	1V	pre	63.6	80.0	63.6	75.0	90.2	93.3	3.2	4.1
			post	54.5	90.0	63.6	70.0	89.4	91.7	3.3	4.4
P10	L2	1V	pre	100.0	85.0	90.9	80.0	98.5	100.0	4.4	4.6
			post	100.0	95.0	100.0	90.0	98.5	93.3	4.7	4.8
P11	L2	1N	pre	72.7	95.0	68.2	90.0	92.4	93.3	3.9	4.6
			post	86.4	95.0	95.5	95.0	93.9	90.0	4.2	4.9
P12	L2	1N	pre	68.2	95.0	54.5	85.0	98.5	93.3	3.6	4.8
			post	63.6	85.0	63.6	85.0	93.9	94.2	4.3	4.9

Note: Scores are reported from the Argument Structure Production Task (ASPT) of the Northwestern Assessment of Verbs and Sentences (NAVS). Tx Lang: treatment language, L2: English, L1: Mandarin; 1N: first treatment = noun, 2N: second treatment = noun, 1V: first treatment = verb, 2V: second treatment = verb; T: target language = trained language, U: target language = untrained language; CU: complete utterance.

Appendix D Table 4. Individual performance on discourse production before and after each treatment cycle.

ID	Tx Lang	Tx	Target Lang	Time point	Narrative Words	Nouns	Verbs	Utt	% CUs
P1	L1	1N	T	Pre	9.3	5.3	1.3	6.7	0.2
				Post	6.7	3.7	0.3	5.3	0.0
			U	Pre	11.3	6.0	0.3	8.7	0.0
				Post	15.7	7.7	1.3	9.7	0.1
		2V	T	Pre	12.3	5.3	1.0	7.3	0.1
				Post	16.3	7.7	0.3	7.7	0.1
			U	Pre	12.0	7.0	1.3	8.0	0.1
				Post	16.0	8.0	1.7	9.0	0.0
P2	L1	1N	T	Pre	35.7	7.7	7.0	5.7	1.0
				Post	40.0	8.7	7.0	6.0	0.9
			U	Pre	42.3	11.0	8.0	5.3	0.8
				Post	32.3	7.3	6.0	4.0	1.0
		2V	T	Pre	36.7	7.7	9.3	6.3	0.9
				Post	27.7	7.0	7.0	5.0	1.0
			U	Pre	39.3	9.3	7.7	4.7	0.9
				Post	33.3	8.3	5.0	4.7	0.8
P3	L2	1N	T	Pre	51.7	14.0	8.0	6.7	0.9
				Post	40.0	12.0	6.3	6.3	0.6
			U	Pre	63.3	14.7	15.0	8.7	0.9
				Post	57.0	13.3	12.7	7.3	0.9
		2V	T	Pre	50.0	15.0	8.3	6.3	0.8
				Post	55.3	15.0	9.0	7.3	0.7
			U	Pre	57.0	13.3	12.7	8.3	0.8
				Post	70.7	15.7	15.7	9.3	0.8
P4	L1	1N	T	Pre	48.3	18.7	6.7	9.7	0.3
				Post	59.0	13.3	8.0	8.7	0.4
			U	Pre	52.7	10.7	11.3	9.0	0.4
				Post	74.7	19.3	17.0	10.0	0.7
		2V	T	Pre	54.0	12.0	7.0	9.3	0.4
				Post	69.3	18.3	7.7	11.3	0.3
			U	Pre	68.7	15.0	15.0	12.0	0.5
				Post	104.3	25.7	20.3	15.0	0.6
P5	L2	1N	T	Pre	45.3	11.7	8.7	5.7	0.8
				Post	27.0	9.0	4.7	4.7	0.9
			U	Pre	41.0	8.0	8.7	6.3	1.0
				Post	36.0	9.7	7.3	5.7	1.0
		2V	T	Pre	44.7	11.0	7.7	5.0	1.0
				Post	48.0	13.0	7.0	7.3	0.8
			U	Pre	42.3	9.7	8.0	5.3	0.9
				Post	50.0	11.3	8.7	7.0	1.0
P6	L2	1N	T	Pre	46.3	9.7	10.3	6.0	0.7
				Post	125.3	22.0	28.0	16.7	0.7
			U	Pre	58.0	11.3	12.0	8.7	0.7

				Post	102.7	20.0	21.0	13.7	0.6
		2V	T	Pre	80.0	18.0	15.3	12.0	0.7
				Post	71.3	18.0	14.3	10.3	0.7
			U	Pre	52.0	9.0	9.3	6.3	0.9
				Post	78.7	14.0	15.3	11.0	0.7
P7	L1	1V	T	Pre	2.0	0.0	1.7	1.7	0.0
				Post	10.7	1.7	3.3	6.0	0.0
			U	Pre	5.0	0.7	0.0	4.0	0.0
				Post	5.3	0.7	0.7	2.7	0.0
		2N	T	Pre	8.7	1.0	2.0	2.3	0.0
				Post	9.0	4.0	2.3	5.7	0.1
			U	Pre	7.7	0.0	1.0	2.7	0.0
				Post	7.7	0.0	0.7	5.0	0.0
P8	L1	1V	T	Pre	2.7	1.0	1.3	1.3	0.0
				Post	9.7	3.7	2.7	5.0	0.1
			U	Pre	3.0	0.0	0.0	2.7	0.0
				Post	4.0	0.0	0.0	2.3	0.0
		2N	T	Pre	4.3	2.7	0.3	3.7	0.1
				Post	7.3	4.0	1.0	3.7	0.1
			U	Pre	4.0	0.0	0.0	2.3	0.0
				Post	4.7	0.3	0.0	3.0	0.0
P9	L2	V	T	Pre	47.3	11.3	7.7	10.0	0.3
				Post	51.3	9.3	8.3	8.0	0.4
			U	Pre	60.3	12.0	10.3	10.3	0.5
				Post	63.7	10.7	12.3	10.7	0.7
P10	L2	V	T	Pre	86.3	19.0	16.0	10.7	0.9
				Post	85.3	18.3	16.3	10.0	0.8
			U	Pre	84.7	17.0	16.0	9.3	0.9
				Post	74.3	13.0	12.7	8.3	1.0
P11	L2	N	T	Pre	34.3	8.0	7.7	6.3	0.8
				Post	50.0	12.7	10.0	7.7	0.8
			U	Pre	26.0	7.0	4.3	7.0	0.6
				Post	56.0	9.3	9.7	7.7	0.9
P12	L2	N	T	Pre	104.0	25.0	22.7	14.0	0.7
				Post	110.0	27.7	23.0	15.7	1.0
			U	Pre	94.0	17.0	20.0	11.7	0.8
				Post	118.3	23.0	20.3	13.7	1.0

Note: Average scores across three tasks: *Cat Rescue, Umbrella, The Tortoise and the Hare*; total number of narrative words, nouns, verbs, utterances (Utt), and percent CUs. Tx Lang: treatment language, L2: English, L1: Mandarin; 1N: first treatment = noun, 2N: second treatment = noun, 1V: first treatment = verb, 2V: second treatment = verb; T: trained language, U: untrained language.

Appendix D Table 5. Individual performance on standardized naming assessments of verbs and nouns.

ID	Tx Lang	Tx	Target Lang	Timepoint	Nouns %	Verbs %
P1	L1	1N	T	Pre	6.5	0.0
				Post	23.9	4.8
			U	Pre	30.4	6.5
				Post	19.6	22.6
		2V	T	Pre	30.4	9.5
				Post	17.4	23.8
			U	Pre	21.7	12.9
				Post	37.0	25.8
P2	L1	1N	T	Pre	82.6	81.0
				Post	82.6	90.5
			U	Pre	84.8	87.1
				Post	87.0	96.8
		2V	T	Pre	82.6	81.0
				Post	67.4	71.4
			U	Pre	84.8	87.1
				Post	39.1	96.8
P3	L2	1N	T	Pre	56.5	61.3
				Post	65.2	80.6
			U	Pre	91.3	76.2
				Post	89.1	85.7
		2V	T	Pre	60.9	80.6
				Post	32.6	87.1
			U	Pre	91.3	95.2
				Post	58.7	85.7
P4	L1	1N	T	Pre	19.6	4.8
				Post	37.0	14.3
			U	Pre	45.7	32.3
				Post	52.2	48.4
		2V	T	Pre	34.8	28.6
				Post	13.0	33.3
			U	Pre	60.9	64.5
				Post	32.6	67.7
P5	L2	1N	T	Pre	60.9	61.3
				Post	60.9	67.7
			U	Pre	65.2	66.7
				Post	65.2	57.1
		2V	T	Pre	63.0	67.7
				Post	67.4	74.2
			U	Pre	63.0	66.7
				Post	32.6	57.1

P6	L2	1N	T	Pre	50.0	67.7
				Post	52.2	71.0
			U	Pre	82.6	90.5
				Post	87.0	95.2
		2V	T	Pre	52.2	67.7
				Post	56.5	87.1
			U	Pre	87.0	95.2
				Post	52.2	90.5
P7	L1	1V	T	Pre	10.9	19.0
				Post	17.4	14.3
			U	Pre	4.3	3.2
				Post	6.5	9.7
		2N	T	Pre	21.7	14.3
				Post	19.6	23.8
			U	Pre	2.2	6.5
				Post	0.0	9.7
P8	L1	1V	T	Pre	6.5	19.0
				Post	23.9	19.0
			U	Pre	0.0	0.0
				Post	0.0	0.0
		2N	T	Pre	19.6	14.3
				Post	23.9	14.3
			U	Pre	0.0	0.0
				Post	2.2	0.0
P9	L2	V	T	Pre	39.1	38.7
				Post	41.3	45.2
			U	Pre	67.4	66.7
				Post	63.0	57.1
P10	L2	V	T	Pre	71.7	87.1
				Post	73.9	100.0
			U	Pre	67.4	90.5
				Post	69.6	71.4
P11	L2	N	T	Pre	41.3	45.2
				Post	45.7	71.0
			U	Pre	34.8	52.4
				Post	50.0	76.2
P12	L2	N	T	Pre	54.3	51.6
				Post	56.5	58.1
			U	Pre	93.5	61.9
				Post	93.5	61.9

Note: Tx Lang: treatment language, L2: English, L1: Mandarin; 1N: first treatment = noun, 2N: second treatment = noun, 1V: first treatment = verb, 2V: second treatment = verb; T: trained language, U: untrained language. Scores of object naming were reported from the Boston Naming Test (n = 30 per language) and the Northwestern Naming Battery (n = 16 per language); scores of action naming were taken from the Northwestern Naming Battery (n = 16 per language) and the Verb Naming Test of the Northwestern Assessment of Verbs and Sentences (n = 21 for L1, n = 31 for L2).

6. OVERARCHING DISCUSSION OF RESULTS AND FUTURE DIRECTIONS

As detailed through Chapters 1-5, bilingual aphasia refers to the loss of one or both languages after brain damage. There has been a rapidly growing Chinese-speaking population in the U.S., leading to a higher risk of developing neurological disorders, such as stroke and dementia (Hoeffel et al., 2012). Lexical-retrieval difficulty is one of many common symptoms in individuals with aphasia. Patterns of lexical impairment can be differentially impacted by a specific grammatical category, i.e., nouns or verbs (Berndt et al., 1997; Kim & Thompson, 2000; Miceli et al., 1984; Zingeser & Berndt, 1990). Nevertheless, the current evidence of bilingual lexical impairment and treatment-induced language recovery has been limited to nouns, without knowing whether similar patterns emerge for verbs. Thus, it is crucial to investigate whether bilingual language recovery and language rehabilitation differ by a specific grammatical category.

Patterns of verb and noun impairment have been previously investigated in BWA, and a verb-noun dissociation in single-word naming has been reported across studies, i.e., a lower naming accuracy for verbs than for nouns (Kambanaros, 2010; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007). This verb-noun dissociation may be attributed to the underlying semantic and morphosyntactic differences between grammatical categories, as verbs in many languages are semantically more abstract and carry richer morphosyntactic structures than nouns (Chapter 2). These previous studies have also found an identical pattern of the verb-noun dissociation in both L1 and L2, regardless of the pre-stroke language proficiency. However, this finding has only been evidenced in bilinguals speaking typologically similar languages (e.g., Greek-English, Turkish-English;

Kambanaros, 2010b), and whether similar patterns of the verb-noun impairment emerge in typologically different languages (i.e., Mandarin-English) is unknown. If the same patterns are observed regardless of the linguistic distance, then one can conclude that the verb-noun dissociation is likely driven by the underlying linguistic differences between word categories, rather than cross-language differences. In addition to naming, discourse analysis has been used as a functional tool to capture lexical impairment in individuals with aphasia (Armstrong, 2000; Linnik et al., 2016). Yet, the relationship between naming and lexical retrieval of nouns and verbs in discourse is unclear (Dai et al., 2012; Faroqi-Shah & Waked, 2010; Kambanaros, 2007). Hence, it is imperative for bilingual aphasia research to investigate patterns of noun and verb impairment in different linguistic contexts (i.e., naming and discourse production), particularly in individuals speaking typologically different languages.

Lexical-retrieval ability is commonly targeted in bilingual aphasia rehabilitation, however, most evidence has come from noun treatment (Chapter 2). Although a few studies to date have targeted verbs in bilingual aphasia treatment, evidence is limited to single-case studies (Knoph et al., 2015, 2017; Li et al., 2020). Moreover, the extent to which treatment and generalization effects are similar in noun and verb treatment remains unclear. In general, studies implementing semantic-based treatment have consistently reported a positive treatment gain and noticeable generalization to semantically-related items (Croft et al., 2011; Kiran et al., 2013; Edmonds & Kiran, 2006; Kiran & Iakupova, 2011; Kiran & Roberts, 2010), in support of spreading activation to items sharing similar semantic features. Notably, since bilinguals have a shared semantic system with two separate lexical systems, training the semantic network of an item has the potential for cross-language generalization to the untreated language. However, evidence of cross-language generalization is relatively inconsistent across studies due to high individual variability in bilingual language history and post-stroke language impairment (Kohnert, 2009; Kuzmina et al., 2019). 2020). Additionally, generalization beyond the single-word level has not been systematically investigated in previous research and evidence is mostly derived from verb treatment (Knoph et al., 2015, 2017; Li et al., 2020). Findings from these studies indicate that verb treatment has the potential for generalization to sentence and even discourse production. Current evidence of bilingual aphasia rehabilitation is mainly constrained to individuals speaking Indo-European languages. Given that the Chinese-speaking population is growing nationwide, there is a great need for bilingual aphasia research to systematically investigate patterns of language impairment and treatment-induced language recovery between nouns and verbs, and thereby help establish the evidence base for language rehabilitation in this population. Thus, studies in this dissertation were undertaken as an initial step to address these critical issues in a large group of Mandarin-English BWA.

According to previous research examining noun and verb retrieval in BWA (Kambanaros, 2010b), a verb-noun dissociation was also expected in both single-word naming and discourse production in Mandarin-English BWA. It was hypothesized that this verb-noun dissociation would be similar in L1 (Mandarin) and L2 (English) in both linguistic contexts. When nouns and verbs were targeted in naming treatment, Mandarin-English BWA were hypothesized to show significant improvement in naming the trained and untrained items, as well as cross-language generalization to the untreated language. Further generalizations beyond the single-word level and to untrained naming tasks were also expected. It was hypothesized that these treatment and generalization effects would differ between training nouns and verbs to varying extents. Particularly, verb treatment was expected to show more generalizations beyond the single-word level and to untrained naming tasks as compared to noun treatment, as verb processing can prime and activate nouns associated with thematic roles (McRae et al., 2005). Table 6.1 illustrates the central hypotheses and findings in Studies 1 and 2.

Overarching hypothesis: patterns of *lexical retrieval* and *treatment-induced language recovery* should be different between nouns and verbs in Mandarin-English BWA.

Table 6.1. Central hypotheses and main findings in Studies 1 and 2.

	Central hypothesis	**Main findings**
	Study 1	
Verb and noun retrieval in single-word naming and discourse production	Verb < Noun, L1 = L2	*Naming*: Verb < Noun, L1 = L2; *Discourse*: Verb < Noun, to a larger extent in L2 and in single-picture description task
	Study 2	
Direct treatment gain	Noun Tx = Verb Tx	Verb Tx > Noun Tx
Within-language generalization	Noun Tx = Verb Tx	Found in Noun Tx, but not statistically larger than Verb Tx
Cross-language generalization	Noun Tx = Verb Tx	Verb Tx > Noun Tx
Generalization to sentences	Verb Tx > Noun Tx	Verb Tx = Noun Tx
Generalization to discourse	Verb Tx > Noun Tx	Noun Tx > Verb Tx
Generalization to untrained naming	Verb Tx > Noun Tx	Noun Tx > Verb Tx

Note: Verb < Noun: worse performance in verb retrieval; L1: Mandarin, L2: English; L1 = L2: similar effect in L1 and L2; Noun Tx = Verb Tx: similar effect in noun and verb treatment; Verb Tx > Noun Tx: larger effect after training verbs than nouns; Noun Tx > Verb Tx: larger effect after training nouns than verbs.

Overall, this dissertation work corroborated a verb-noun dissociation across linguistic contexts in both languages of Mandarin-English BWA (Study 1). It also provided strong evidence that semantic-based treatment promoted direct treatment gains and generalizations within and beyond treatment, but to varying degrees between training nouns and verbs (Study 2). The implication of this work for future research in bilingual aphasia recovery and language rehabilitation will be discussed in the following sections.

Regarding lexical retrieval of nouns and verbs, findings in Study 1 suggest that verbs are more impaired than nouns in both L1 and L2 in Mandarin-English BWA. This result supports previous studies in bilinguals speaking typologically similar languages (Kambanaros, 2010a; Kambanaros & van Steenbrugge, 2006; Poncelet et al., 2007), and suggests that the verb-noun dissociation may not be driven by language-specific properties. Instead, this dissociation between nouns and verbs could be due to a weakened link between semantic and lexical representations for verbs (Van Hell & De Groot, 1998). Verbs in general are less imageable than nouns, and previous studies have reported no verb-noun dissociation when *imageability* was controlled for in noun and verb naming (Bird, Howard, et al., 2001; Poncelet et al., 2007; Kevin Shapiro & Caramazza, 2003). Although Study 1 attempted to account for imageability and found no significant difference in naming accuracy between nouns and verbs, findings should be interpreted with caution as imageability ratings in English were used as approximate measures for Mandarin. Hence, future research should systematically investigate the effect of psycholinguistic factors on noun and verb retrieval in each language and help better understand the underlying linguistic mechanisms of the verb-noun dissociation.

The same verb-noun dissociation was identified in discourse production, but to a larger extent in L2 than in L1. This result suggests a complicated pattern of lexical impairment when tasks are cognitively and linguistically demanding. However, the cross-linguistic difference in noun and verb dissociation became smaller in individuals with higher WAB-AQ, indicating that post-stroke language impairment may be a determiner of lexical retrieval in linguistically complicated tasks. Future research should continue examining the role of aphasia severity in noun and verb retrieval by controlling for the level of post-stroke language impairment. Additionally, our findings showed a larger magnitude of the verb-noun dissociation in single-picture description. This type of task typically imposes higher cognitive-linguistic demands than others (i.e., storytelling, sequential pictures; Fergadiotis & Wright, 2014), suggesting the need to engage more higher-level cognitive control abilities. It will be crucial for future research to investigate the influence of both linguistic and nonlinguistic cognitive skills (i.e., memory, executive function, verbal short-term memory; Gilmore et al., 2019; Gray & Kiran, 2016) to gain a more comprehensive view regarding lexical impairment in BWA. Altogether, findings from Study 1 indicate that the dissociation between grammatical categories most likely stems from the shared semantic system in BWA. When the cognitive-linguistic demands increase, post-stroke language impairment and task complexity may be crucial predictors of lexical retrieval in L1 and L2. These findings provide preliminary evidence of noun and verb retrieval in Mandarin-English BWA, which sets as solid foundation for interpreting rehabilitation outcomes in Study 2.

When these Mandarin-English BWA underwent semantic-based treatment targeting noun and verb retrieval, positive treatment and generalization effects were found across participants (Study 2). Significant improvements on the overall aphasia severity and lexical retrieval as reflected by the raw scores on the standardized assessments further substantiate the effectiveness of semantic-based treatment. During treatment, despite the typological differences between Mandarin and English, the positive treatment gain in the trained items supports the robust effect of semantic-based treatment in Mandarin-English BWA. Although both noun and verb treatment showed remarkable treatment gains, training verbs promoted greater improvement than training nouns. As mentioned in Chapter 2, verbs are more difficult to access than nouns due to weaker cross-linguistic connections at the conceptual level (Van Hell & De Groot, 1998). Hence, targeting the weaker semantic network for verbs should promote more treatment gains as compared to nouns. Specifically, training feature categories of *subject* and *object* could further facilitate verb retrieval as thematic roles are part of the semantic representations of a verb (Edmonds et al., 2009; Li et al., 2020; McRae et al., 2005; Wambaugh & Ferguson, 2007). Theoretically, training semantic features of an item should also generalize to semantically-related items (Boyle & Coelho, 1995; Boyle, 2004; Coelho et al., 2000), but this within-language generalization was only observed in noun treatment. Although our stimuli were controlled for psycholinguistic factors (i.e., frequency, familiarity, number of syllables), other factors such as instrumentality (Bastiaanse & Jonkers, 1998; Jonkers & Bastiaanse, 2006; Kambanaros, 2009) and somatotopic information (Faroqi-Shah et al., 2009) may also affect the semantic relatedness across verb stimuli and hamper the within-language generalization. Another factor that may cause no within-language generalization is the specificity of verb features (Faroqi-Shah et al., 2009). Training abstract concepts with general features (e.g., *using a tool*) may not be sufficient to promote the activation of semantically-related verbs. Instead, using verb-specific features that directly link to the corresponding action name should strengthen the semantic network to promote lexical access to semantically-related items. Therefore, it is important for future research to control for potential factors that may impact the semantic relatedness across verb stimuli, and also include verb-specific features to promote within-language generalization.

Training nouns and verbs further showed robust cross-language generalizations in our participants. This finding corroborates previous theories in bilingual lexical processing, which posit spreading activation from the shared semantic system to lexical representations in both L1 and L2 (Chapter 2). The cross-language generalization was even larger when training verbs than nouns. Given that the degree of cross-linguistic overlap at the semantic representation level is lower for verbs than nouns (Van Hell & De Groot, 1998), training verbs may cause less between-language interference and lead to greater cross-language generalization (Costa et al., 2006). It is also possible that since verbs in Mandarin do not carry rich morphosyntactic structures, the lexical access to verbs in L1 may be easier or faster. Hence, individuals who were trained in L2 should show a larger cross-language generalization than those trained in L1 during verb treatment. Although individual effect sizes in the untreated language support this presumption, evidence is limited to three participants. Hence, future research should increase the sample size in each treatment group and continue investigating the effect of language-specific properties on cross-language generalization.

Widespread generalizations beyond the single-word level were also observed following both noun and verb treatment. These results are promising in bilingual aphasia rehabilitation and suggest that strengthening the semantic network of both nouns and verbs has the potential for generalization to sentence and discourse production (Lerman et al., 2019; Li et al., 2020). In sentence production, training nouns and verbs showed generalization to a similar extent, suggesting that repeated feature analysis of verbs and nouns may have strengthened lexical access to all syntactic structures, i.e., subject, verb, and object (Edmonds, 2016; Edmonds et al., 2014). In discourse production, noun treatment led to generalizations to overall lexical retrieval and complete utterances, whereas verb treatment mainly generalized to lexical retrieval. Recall that verbs were more impaired than nouns in discourse production at baseline (Study 1), so our participants may need more verb treatment to strengthen their semantic network in order to promote greater generalization to discourse production. Moreover, generalization to discourse has been mostly reported following verb treatment in a sentence context (VNeST; Edmonds et al., 2009). Hence, it may be necessary to integrate verbs into sentences during treatment to facilitate generalization to discourse. These findings also imply the need to increase the treatment intensity for steps associated with sentence production (i.e., Step 6). Future research should systemtatically investigate the effect of each treatment step to identify the specific ingredients driving generalization effects.

Finally, Study 2 captured generalization to untrained naming tasks following both noun and verb treatment, suggesting that targeting the semantic network aids in better overall lexical retrieval in Mandarin-English BWA. Surprisingly, noun treatment also showed greater generalization to untrained verb naming as compared to verb treatment. In general, verbs are a powerful source of semantic constraint (Chapter 2; McRae et al., 2005), meaning that thematic roles are constrained to specific semantic categories. Hence, training verbs did not generalize to untrained nouns as expected. On the other hand, training feature categories of an object (i.e., function, characteristics, physical attributes, category, location) may have the potential for strengthening the semantic connections to different events, leading to increased activation of untrained verbs (Lancaster & Barsalou, 1997). This generalization effect can also be attributed to syntactic differences between Mandarin and English. The pro-drop feature in Mandarin makes verbs in a more salient position, thus resulting in greater generalization to untrained verb naming (Huang, 1989). When the generalization effect was further examined between training in L1 and L2, our results showed two interesting patterns: training nouns in L2 generalized to untrained verbs in the treated language, i.e., L2, whereas training nouns in L1 generalized to untrained verbs in the untreated language, i.e., L2. When participants were trained in L2, their L1 inhibition might become stronger over the course of treatment, hence generalization was observed in the treated language (Meuter & Allport, 1999; Linck et al., 2008). But when individuals were trained in L1, the dominant language, the semantic interference elicited between nouns and verbs may exceed the between-language inhibitory control, leading to generalization to the untreated language (Kiran et al., 2013). These findings suggest different mechanisms involved in treatment generalization in Mandarin-English BWA. Future research should continue exploring these mechanisms by increasing sample sizes in each treatment group. It is also important to investigate the effect of other individual factors, such as language proficiency and post-stroke impairment (Kuzmina et al., 2019; Peñaloza & Kiran, 2019) to help provide a comprehensive view of individual heterogeneity in bilingual language rehabilitation.

Future work should build on findings from Studies 1 and 2 by conducting psycholinguistic and treatment studies with larger participant samples. To better understand the linguistic mechanisms underlying noun and verb impairment, systematic error analysis can be conducted to examine types of speech errors in single-word naming and discourse production. To promote greater treatment generalizations, stimuli should be well controlled for conceptual factors that may potentially impact their semantic relatedness, and features should be controlled for their specificity related to the target name. In addition, the effect of individual and language-specific factors should be uncovered in future research to help better understand the differences in training nouns and verbs. These factors include pre-stroke language proficiency, linguistic and nonlinguistic cognitive control abilities, and morphosyntactic differences between Mandarin and English. This work will shed light on the impact of individual heterogeneity in bilingual aphasia recovery and language rehabilitation, which is key to diagnosis and planning individually tailored treatment for BWA. Finally, treatment ingredients (i.e., naming, feature analysis, word association, and sentence production) should be systematically investigated to help identify the active ingredients that may drive the differences in treatment effects between training nouns and verbs (Boyle et al., 2022).

In sum, this dissertation demonstrated that (1) verbs are more impaired than nouns in single-word naming and discourse production in Mandarin-English BWA (Study 1), and

(2) semantic-based treatment for nouns and verbs promotes successful lexical retrieval within- and beyond treatment, but patterns of treatment and generalization effects may vary between word categories. These findings support the overarching hypothesis that patterns of lexical retrieval and treatment-induced language recovery are different between training nouns and verbs in Mandarin-English BWA. Yet, this hypothesis should continue to be refined within future studies in which factors specific to stimuli and individuals are controlled to maximize treatment generalizations for this bilingual population.

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8. CURRICULUM VITAE

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