HOW DOES BILINGUALISM MATTER?

A META-ANALYTIC TALE OF TWO HEMISPHERES

A Dissertation

by

RACHEL GAYLE HULL

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2003

Major Subject: Psychology

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ABSTRACT

How Does Bilingualism Matter?
A Meta-Analytic Tale of Two Hemispheres. (May 2003)
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The present investigation evaluates the effects of multiple language acquisition history on brain functional organization for language. To address a range of findings concerning the functional cerebral lateralization of the native (L1) and second languages (L2) of bilinguals, a meta-analysis was conducted on 71 studies that used behavioral paradigms to assess bilingual laterality. The predictive value of a number of theoretically identified moderators of cerebral asymmetry for language was assessed, namely, the age of second language (L2) acquisition, fluency in theL2, participant sex, experimental paradigm, linguistic task demands, relatedness of L1 and L2 structures, and context of language use. The results revealed no differences in the laterality of first and second languages within L2 acquisition age groups. Of the moderators tested, age of L2 acquisition was identified as the most reliable predictor of the direction of laterality. The conditions under which systematic similarities and differences in language lateralization among bilingual subgroups emerge are discussed in terms of implications for current models and theories concerning the functional organization of language in the bilingual brain.

DEDICATION

With most sincere thanks and warmest regard for the extraordinary group of mentors who contributed their unique talents and perspectives to the unfolding of this project. I have been exceedingly fortunate to have worked with these generous individuals who committed much time and patience toward my training and academic development. I wish to acknowledge each one with my heartfelt gratitude.

To Jyotsna Vaid, my chair and my friend, for investing her intellect, time, and effort to mold me into a critical thinker, for showing me how to examine the larger issues, for instructing me in the art of conceptual writing, and for introducing me to the breadth and depth of the intriguing field of psycholinguistics. I am deeply appreciative of her ongoing efforts to guide and prepare me as a researcher. We have traveled a long road together and shared many laughs along the way. I look forward to continuing the journey.

To Steve Smith and Heather Bortfeld, whose mentorship, friendship, and encouragement have been priceless. I am profoundly indebted by their selfless dedication in helping me succeed, their readiness to offer their professional expertise and experience, and their active participation in preparing me for the practical aspects of academic life, all of which are lessons that will follow and serve me without end.

To Wendy Wood, for introducing me to the rigors and rewards of meta-analysis. Her early teachings helped shape this project, and her continued involvement has been absolutely instrumental to its fruition. I am deeply grateful for her personal interest and guidance throughout the process.

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You are all most dear to me, and I hold each of you in the highest esteem. You have provided the most excellent of professional and personal models that I aspire to follow. Thank you for a wonderfully positive experience.

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INTRODUCTION

The nature of the brain-language relationship has interested neurologists and language researchers for well over a century. Lesion deficit studies have been the primary basis for the view that the left cerebral hemisphere (LH) is specialized for language, particularly grammar and phonology. It has subsequently been theorized that the right hemisphere (RH) is important for the processing of semantic and pragmatic aspects of language. The vast majority of empirical studies of brain organization of language have been conducted on single language users. Of principal interest to the present study is whether or how differences in language experience associated with the acquisition of two or more languages (hereafter termed bilingualism), influence brain functioning for language in terms of relative hemispheric participation. Research with nonhuman species has shown that brain organization is extremely sensitive to early sensory experience, in particular, showing differences in response to impoverished vs. enriched sensory stimulation (e.g., Blakemore & Cooper, 1970; Hubel, Wiesel, & LeVay, 1977). Similarly, research with humans who experienced early sensory deprivation in one or another sensory modality has pointed to subsequent alterations in brain functional organization (Neville, Coffey, Lawson, Fischer, Emmorey, & Bellugi, 1997; Burton, Snyder, Conturo, Akbudak, Ollinger, & Raichle, 2002). Studying variations in the nature and onset of language exposure offers a unique window into the influence of language experience on brain functioning. Given that bilinguals vary widely in age, manner, and stage of acquisition of the second language (L2), they present an ideal population to address questions about biobehavioral concomitants of language experience. Moreover, comparisons of neuropsychological differences associated with early versus late (second) language acquisition are of particular theoretical relevance to the controversy about the existence of a sensitive period for language mastery (see Johnson & Newport, 1989; Lenneberg, 1967; Newport, Bavelier, & Neville, 2001).

This dissertation follows the style and format of The Psychological Bulletin.

The present research sought to test the claim that multiple language acquisition alters the pattern of brain functional asymmetry for language[1]. To accomplish this goal, a meta-analysis of all available experimental studies of cerebral lateralization for language in brain-intact bilinguals was conducted. A total of 77 studies met our inclusion criteria. The following specific questions were examined: 1) Does cerebral asymmetry for each language vary as a function of the age at which bilinguals acquire each of their languages? 2) Does lateralization vary as a function of the fluency level attained in each language? 3) Regardless of group, are tasks that involve language processing at a global level lateralized differently than those involving local, word level processing? 4) Are the two languages of bilinguals lateralized similarly or differently? 5) Is the pattern of lateralization influenced by whether a bilingual's two languages are structurally or typologically similar vs. dissimilar? 6) Is lateralization influenced by response mode, i.e., whether responses are articulated vs. given in some other form? 7) Finally, are bilingual men lateralized differently from bilingual women?

Working Definitions of Cerebral Asymmetry and the Sensitive Period

Before proceeding further, it is important to state our working definitions of a few key terms. In the present paper, "cerebral functional asymmetry" and "language lateralization" both refer to the condition wherein one hemisphere of the brain is relatively more active during performance on a verbal task than the other hemisphere. The canonical pattern is left hemisphere (LH) dominance, i.e., where the left hemisphere is more active relative to the right hemisphere (RH) during verbal tasks.

The term "sensitive period" in this paper refers to a time of maximal brain plasticity during language development. During this period, functional lateralization is thought to be most influenced by variations in the timing of exposure to language. One

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[1] It should be noted that the vast majority of the studies included in this meta-analysis concerned bilingual users. We recognize that recent research has sought to distinguish trilinguals and multilinguals in general from bilinguals (Cenoz & Jessner, 2000). For our present purposes, however, we will use the terms "bilingual" and "multilingual" interchangeably.

of the interests of the present research is whether there are differences in hemispheric asymmetry for first and/or second languages as a function of whether L2 exposure occurred from infancy up to age six, versus during or after adolescence, versus at some intermediary point in childhood.

Sectional Organization of the Present Paper

The literature on bilingual language lateralization is extensive. Several hundred experimental studies have been conducted, and nearly as many theoretical and review papers exist that address possible patterns in laterality. A major challenge to interpreting this literature has been the extreme variability in findings, participant populations, testing methodologies, and linguistic tasks. The present research provides a theoretical overview of the most studied aspects of this complex literature, followed by a quantitative, meta-analytic synthesis of all relevant experimental data. Our discussion of the meta-analytic findings makes reference to theoretically-grounded moderator variables that have been proposed to account for the diversity of results reported in the literature. The findings provide insights into the conditions that underlie the functional organization of language in the bilingual brain. I discuss how such conditions relate to current theoretical issues in bilingualism and brain functioning. The paper concludes with suggestions for some useful directions for future bilingual laterality research. The paper is divided into five major sections, as follows:

1. Lateralization for Single Language Systems

In this section, the historical bases for hypotheses in the mainstream language lateralization literature (i.e., literature that has focused on brain asymmetries for language in monolinguals) are reviewed. Clinical evidence that underlies theories concerning a maturational timetable for early language development as well as experiential constraints on cognitive development is discussed.

2. Why Bilingualism Might Matter for Language Lateralization

Having laid out the relevant evidence underlying theories of monolingual language lateralization, next presented is evidence that suggests the case might be different for bilinguals. In particular is discussed how brain maturational considerations may interact with cognitive processing strategies to alter language lateralization in users of two or more linguistic systems.

3. From Lesion Data to Bilingual Neurocognitive Perspectives

This section reviews evidence from the aphasia literature concerning differential consequences for brain functional organization of language arising from the acquisition of two linguistic systems. Connections are then drawn from research with brain-damaged and healthy populations to theoretical moderators of language lateralization in bilinguals. In addition, methodological challenges arising from the study of several moderators are discussed.

4. Prior Meta-Analyses of Bilingual Laterality

This section reviews the goals and findings of previous meta-analytic results conducted on certain subsets of the larger corpus of bilingual laterality studies.

5. The Present Research

In this section, the methodology, variables considered, sample of studies, and the meta-analytic findings concerning functional language lateralization in bilinguals are presented. Following a summary of results is a discussion of the possible interpretations of the meta-analytic findings and their consequences for theories of bilingual laterality. I conclude with some suggestions for how the meta-analytic findings may inform future psycholinguistic research with bilinguals.

LATERALIZATION FOR SINGLE LANGUAGE SYSTEMS

Neurological Maturation and Hemispheric Functioning

An early effort at understanding the brain-language relationship began with a perspective discussed by Eric Lenneberg, who proposed that "man's capacities for language acquisition change with age" (1969, p. 9). In reviewing clinical studies of language deficits, Lenneberg noted that the majority of cases in which left hemisphere lesions caused irreversible language disruption involved post-pubertal patients, whereas younger children who suffered left-hemisphere lesions were often able to recover full language function. He further noted that longitudinal studies of the linguistic progress of mentally handicapped children and deaf children suggested that language development is arrested after the onset of puberty (see also Fromkin, Krashen, Curtiss, Rigler, & Rigler, 1974).

Based largely on cases of children born with mental handicaps and of children and adults with brain trauma, Lenneberg argued that the "normal" development of language depends in large part on the age of the learner, with younger learners being better able to master language than older ones (see also Bialystok, 2001; Birdsong, 1999; Johnson & Newport, 1989; Penfield & Roberts, 1959). Parenthetically, this argument of age-related sensitive periods for the development of different components of language fits well with a separate developmental observation that vocabulary and phonology are acquired early and rapidly whereas syntactic skills are acquired more gradually and later in childhood (see Johnson & Newport, 1989; Birdsong & Molis, 2001; Fromkin et al., 1974).

The notion of a sensitive period for language acquisition is difficult to test with monolinguals, as it is rare for a first language to be acquired after childhood. Nevertheless, two particular such cases support such a notion. One of these is the case of Genie, a socially isolated child who received little or no social contact (including linguistic input) until after the onset of puberty, when her predicament was discovered by a social worker. Upon discovery, Genie had no language and had experienced minimal human interaction, although it was determined that her language deficit was not the result of a physical abnormality. Interestingly, Genie's linguistic development subsequently never reached normal levels despite an established absence of physical or mental disease and fairly typical progress in general cognitive development (Fromkin et al., 1974; Curtiss, 1977).

Another exceptional case on record of late first language development is that of Victor, the "wild boy," who was discovered living in the woods of Averyon, France around 1800. Victor's is an exceptionally strong case of complete language deprivation, as he reportedly lived without any human interaction until about the age of 12 (see Itard, 1964). Victor had no language at all when he was discovered. Like Genie, Victor learned to communicate verbally but was never able to master phonology or syntax despite the best attempts on the part of his devoted physician.

Whereas Genie and Victor provide compelling evidence for a sensitive period for language development, they are but two select, and probably rare, cases. Other evidence in support of age-related differences in brain plasticity for language acquisition emerges from clinical findings that monolingual children under five years of age are more often able to develop normal language function after left hemispherectomy than are their adult counterparts (see Schneiderman, 1983). Still other research that supports the notion of brain plasticity for language is the finding that language deficits occur more often in young children who sustain RH damage than in adults with similar RH lesions (see Dennis & Whitaker, 1976).

Age-related differences in the functional consequences for language processing after brain damage may reflect the fact that the human cortex and corpus callosum continue to develop in children through the age of five, with the brain becoming increasingly less plastic after that age (see Joseph, 1982; Geschwind, 1974; Witelson, 1977). It follows, then, that the right hemisphere may be relatively more involved in a child's language processing than an adult's. Taken together, the neurological and language lateralization accounts provide a basis for expecting that, in general, brain damage during early brain development may have different consequences for language processing than damage sustained later in life.

Specific evidence for age-related differences in brain functional organization for language in monolinguals was reported in a longitudinal study of 53 children with peri- and prenatal focal brain injury who were tested at three intervals from the time they were 10 months of age through 44 months (Stiles, Bates, Thal, Trauner, & Reilly, 1998). The study showed the surprising finding that comprehension problems (vs. production deficits) occurred more often in the children with RH damage, whereas LH injuries to the posterior temporal region, i.e., Wernicke's area, were associated with delayed language production but no measurable comprehension deficits. As Stiles et al. pointed out, these results are directly opposed to the typical deficit pattern for adults with similar left posterior temporal lesions. That is, adults with late focal injury to Wernicke's area typically display language comprehension deficits but remain in the normal range on production. Stiles et al. concluded that neural systems underlying language acquisition in young children might differ from neural substrates of language processing in adults, although the generalizability of clinical cases to the brain-intact population is uncertain.

The discussion of clinical evidence and subsequent theories pertaining to the possibility of maturational constraints on neurological development provide adequate rationale to further examine age-related consequences for functional language processing. While these studies, relying primarily on clinical populations, are instructive, ultimately one would like to show converging evidence from healthy populations, given that early brain injury may have resulted in reorganization of brain function. The study of bilinguals offers a unique means to evaluate brain maturational constraints on the biobehavioral aspects of languages acquired at different temporal points in the lifespan.

Cognitive Processing and Hemispheric Functioning

In addition to proposed differences in brain functional organization for language arising from neurological maturation, cognitive change is also expected as the cerebral hemispheres develop specialized strategies for processing information, including language (e.g., Goldberg & Costa, 1981; Ullman, 2001; Zevin & Seidenberg, 2002). Many dichotomies have been proposed to characterize presumed differences in cognitive processing between the two hemispheres, but, in general, left hemisphere processing has been characterized as linear, analytic, and computational, whereas right hemisphere processing has been characterized as holistic, Gestalt-like, and context-dependent (see Moscovitch 1977; Grosjean, 1989; Fabbro, Gran, Basso, & Bava, 1992; Zaidel, 2001).

Here again, clinical data offer some clues about proposed hemispheric differences in cognitive processing strategy. Drewe (1974) reported that patients with lesions to the right frontal lobe resulted in more perseveration errors on the Wisconsin Card Sorting task, whereas more non-perseveration errors were associated with left frontal lesions. Similar findings emerged in another study involving patients with right or left temporal lobectomy (Rauch, 1977). The right-lobectomized (left hemisphere intact) patients persisted with previously generated strategies to solve new problems, whereas the left-lobectomized (right hemisphere intact) patients changed strategies frequently and tended to approach each problem as a new task.

Whereas the two studies referenced above were designed to test the consequences of brain damage on basic cognitive function, the results are supportive of the idea that, in general, the left hemisphere may make better use of previously learned strategies, while the right hemisphere may be better suited for synthesizing an array of earlier experiences to create new strategies. Indeed, such ideas have been proposed in the mainstream language laterality literature. Specifically, the right hemisphere has been proposed to be preferentially involved in the acquisition of new cognitive strategies, while well-routinized strategies are thought to be within the competency of the left hemisphere (Goldberg & Costa, 1981; Ullman, 2001).

Other research with brain-intact individuals that has more directly focused on language processing has also produced results that are consistent with the notion of processing differences between the two hemispheres. For example, a left hemisphere specialization for processing speech and language-related auditory information has been suggested, at least in monolinguals, on whom the majority of such research has been conducted. In a series of auditory evoked potential experiments, Molfese (1977) showed that preverbal infants, children from four to 12 years of age, and adults from 23 to 29 years of age all showed increased LH responding when listening to syllables and words, and increased RH responding to music or nonspeech noise. Interestingly, the infant group showed significantly more LH activation to speech sounds than did either the child or adult groups, who did not differ. More recent findings with preverbal infants have suggested that the LH is preferentially implicated in mouth asymmetries associated with the production of monolingual infant babbling as compared to mouth movements during other oral activities, such as crying and smiling (Holowka & Pettito, 2002).

Additional support for the notion that the LH may be specialized for speech processing comes from studies showing that the planum temporale (a brain region including the posterior speech areas) is larger at birth in the LH than in the RH (see review by Moscovitch, 1977). Recent neuroimaging studies have also linked the comprehension of speech sounds to areas of increased LH activation (e.g., Zatorre & Binder, 2000). Furthermore, work with congenitally deaf individuals has indicated that the left superior temporal gyrus (STG), which is typically associated with speech processing in hearing monolingual persons, is also activated during sign language processing (Pettito, Zatorre, Gauna, Nikelski, Dostie, & Evans, 2000). Pettito et al. suggested that one interpretation of these results could be that the functional role of the left STG was reorganized in congenitally deaf individuals to process the visual “speech” information in sign language as a result of the deprivation of auditory speech information.

A recent meta-analysis of 64 behavioral language laterality studies with brain-intact monolinguals revealed a reliable left hemisphere effect for speech production (Medland, Geffen, & McFarland, 2002). Interestingly, the asymmetry was more pronounced for men relative to women overall. The authors suggested that sex differences in laterality for speech production might reflect differences in brain physiology, brain functional organization, or simply in the use of different cognitive strategies for approaching the laterality tasks.

Taken together, the clinical data and studies with brain-intact populations support a separation in the functional strategies of the two cerebral hemispheres for at least certain types of cognitive processing in monolinguals, including speech. However, as with research on age-related differences in the development of functional brain asymmetries in monolinguals, much of the available data on the development of strategy-related asymmetries in monolinguals has also been based on clinical data or, more recently, on correlational neuroimaging data. In what follows, I review behavioral and neuroimaging findings from the bilingual language lateralization literature in both clinical and brain-intact populations.

WHY BILINGUALISM MIGHT MATTER FOR LANGUAGE LATERALIZATION

Maturational Considerations in Bilinguals

An argument for brain maturationally-based differences in the organization or lateralization of acquisition for second vs. first languages has been postulated by many language researchers and theorists. It has been hypothesized that, on the assumption that the human brain continues to develop until puberty, a language that is acquired after brain maturation is complete may show different neural mediation than that characterizing languages acquired while the brain is still developing (Penfield & Roberts, 1959; Genesee, 1982; Obler, Zatorre, Galloway, & Vaid, 1982; Johnson & Newport, 1989; Birdsong & Molis, 2001; Sussman, Franklin, & Simon, 1982; Birdsong, 1999; Perani, Dehaene, Grassi, Cohen, Cappa, Dupoux et al., 1996; Tan, Spinks, Feng, Siok, Perfetti, Xiong et al., 2003). Greater biobehavioral language processing differences are expected as more time elapses between the acquisition of the first and second linguistic systems.

Two recent neuroimaging studies with brain-intact bilinguals are consistent with claims of age-related changes in the neurological substrates that underlie language. One study used functional magnetic resonance imaging (fMRI) to measure brain activity patterns in early Chinese-English bilinguals (L2 acquired before age six) during silent word reading in each of the two languages (Savio, Wong, Spinks, Liu, Chen, & Tan, 2002). The results showed a high degree of overlap in cortical activation across the two languages, despite the marked difference between the phonological and semantic systems of the English and Chinese languages. The other study used positron emission tomography (PET) to evaluate brain activity during word listening in Italian-English bilinguals with differing ages of English acquisition (Perani et al., 1996). The results of this study showed a separation in cortical areas activated during processing of the L1 and L2, but only for those bilinguals who learned the L2 after the age of seven (see also Abutalebi, Cappa, & Perani, forthcoming). Taken together, the studies reveal a greater similarity for neurological functioning in L1 and L2 processing as a function of simultaneous early L2 acquisition, but less similarity when the two languages were learned years apart.

Although there are some serious interpretive problems with neuroimaging as a source of evidence about language representation (see Vaid & Hull, 2002), imaging studies do furnish data about cerebral activity at a different level than that available in behavioral studies per se. Insofar as neuroimaging studies reflect the workings of the intact brain in vivo, the two imaging studies described above suggest that different patterns of brain activity during language processing may be correlated with neural differences underlying age of onset of second language acquisition, or that they are correlated with other experiential differences in language use over the lifetime. Unfortunately, although the number of imaging studies with bilinguals has now exceeded 40, very few of these studies have been designed in a way to allow comparisons of bilinguals with monolinguals, or of bilinguals with other bilinguals differing in age of onset of language exposure, thereby making this source of evidence not very informative about individual differences in brain organization related to language experience.

Cognitive Considerations in Bilinguals

Quite apart from brain maturational considerations, one may also expect differences between bilinguals on the basis of possible differences in cognitive architecture or processing strategy associated with bilinguality. It has been suggested, for example, that the process of acquiring two languages may promote the development of cognitive strategies for resolving any interlingual interference that may arise from contrasting phonologies or grammatical rules (Ben-Zeev, 1977; see also Genesee et al., 1978). Not only might strategies for storing and accessing two linguistic systems be different from those associated with processing a single language system, there may also be different lexical and conceptual representations within bilinguals as a function of their context of language acquisition or mode of language use. Weinreich (1968) proposed three possible modes of conceptual organization in bilinguals: a compound form, a coordinate form, and a subordinate form. Lambert (1969), among others, suggested that these modes might in turn arise from differences in the context in which the languages were acquired. A compound form of internal organization may characterize bilinguals who acquired both languages simultaneously and in similar contexts during early childhood, whereas a coordinate or subordinate form may characterize bilinguals who acquired the second language much later than the first and in a separate setting (e.g., at school).

An alternative to a "compound" form of language representation has recently been proposed for bilingual children acquiring the two languages concurrently. In contrast to suggestions that young children exposed to two languages indiscriminately mix and confuse words in their two languages initially, the evidence from recent research on early bilingual children shows instead that bilinguals who acquire both languages early in life and in similar learning environments develop <u>autonomous</u> memory representations for the two languages (J. Paradis & Genesee, 1996). According to the autonomous perspective, each language of a bilingual child should develop similarly to the same languages in monolingual children. The <u>interdependent</u> view, on the other hand, posits a single underlying conceptual system that subserves both languages and in which each language influences the other. This condition would give rise to language development in early bilinguals that is qualitatively different from the development of either language in monolinguals. At least for the acquisition of syntax, Paradis and Genesee have reported empirical support for the autonomous view.

Empirical support from adult bilinguals has been mixed for the integrated (i.e., compound or interdependent) vs. independent (i.e., coordinate or autonomous) views of bilingual language representation (see review by de Groot, 1993). In some cases, early bilinguals have been found to produce similar responses to the <u>meaning</u> of homologous words in each language (suggesting that they accessed a single conceptual representation), whereas the less similar responses of late bilinguals indicated that they accessed separate meaning representations for homologous words in each language (Lambert & Rawlings, 1969). Similarly, a recent study of long-term cross-language word priming again showed that, when the task required bilinguals to access the conceptual meaning of a word in one language (i.e., decide whether the word is a living thing or not), its translation equivalent was primed in the other language, even after a delay (Zeelenberg & Pecher, in press). However, these results do not map well to the compound-coordinate dichotomy, as the bilinguals tested in this study had acquired the L2 at school after the age of 10, and would thus be considered "coordinate" bilinguals with separate representations for the two languages. Indeed, Zeelenberg and Pecher interpret their results to support a shared conceptual representation of homologous L1 and L2 word meanings.

Other studies that used a lexical decision paradigm to test word form repetition priming have reported a failure to support a single storage system in compound (i.e., early) bilinguals. For example, Larsen, Fritsch, and Grava (1994) reported that lexical decision to words in one language preferentially primed words in the same language, but not homologous words in the other language, thus failing to support a shared representation for first and second languages in early bilinguals. Another study used interlingual homographs (identical word forms but different L1 and L2 meanings) as primes, but again found no evidence of cross-language priming (Gerard & Scarborough, 1989). The results of cross-language priming studies such as these have been interpreted as evidence for separate lexicons for each of a bilingual's two languages.

It has been suggested that the disagreement in findings from cross-language priming studies may stem from differences in task demands (Gollan & Kroll, 2001; Heredia & McLaughlin, 1992). Specifically, studies using tasks that are sensitive to semantic processes (e.g., Zeelenberg & Pecher) have typically reported a cross-language priming effect and inferred a single memory representation for language, whereas studies with tasks that are sensitive to lexical features of words (e.g., Gerard & Scarborough, 1989) generally report evidence for separate memory representations for the two languages.

Based largely on such findings, models of bilingual memory representations for first and second languages have made distinctions between the processes involved in accessing lexical/grammatical versus conceptual/semantic levels of representation.

Current models of the bilingual mental lexicon take a processing rather than a representation approach. Specifically, language information has been proposed to be stored in an hierarchical fashion, with acceptable word form, pronunciation, and syntactic features in each language being represented in independent lexicons, and the conceptual representation of word meanings, regardless of language order, being held in a separate store.

One particular processing view of bilingual memory representations has been extensively discussed in recent work in bilingual lexical access and is therefore summarized here.[2] The Revised Hierarchical Model of Bilingual Memory (Kroll & Stewart, 1994), states that word-processing begins by accessing either the L1 or the L2 lexicon, with the latter store being of limited capacity relative to the former because bilinguals are assumed to have less information about meanings associated with L2 words. The model posits that meaning will be attached to an L2 word by first translating it into the L1 word and then retrieving conceptual information that is connected to the L1 word. In this way, links from the L2 to the L1 lexical stores develop strong and automatic connections, but connections between the less frequently used L1-L2 route are weak. Moreover, links from the L1 lexicon to the conceptual store are strong, but links from the L2 lexicon are weaker and fewer in number. Given these assumptions, the model predicts that, if the L1 lexicon is engaged, then direct and fast access to the conceptual level of representation is allowed. However, if the L2 lexicon is utilized, then access to word meaning is generally indirect. That is, first the homologous word in the L1 lexicon is automatically activated, and then access to the conceptual store is gained by way of the L1 lexical entry. Thus, according to this model, access to the conceptual level for L2 words generally requires a longer, indirect process. Consequently, the model predicts that cross language lexical priming should be fast in the L2-L1 direction, but minimal or nonexistent in the L1-L2 direction. A similar pattern of results should obtain for cross-language semantic priming.

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[2] A complete discussion of models and theories regarding bilingual memory representations is beyond the scope of the present paper, but see reviews by de Groot (1995) and Grosjean (1998).

Limited empirical support for the Revised Hierarchical Model has been reported. Dufour & Kroll (1995) had fluent and nonfluent bilinguals decide whether a target word was a member of a given category, where target items and category names were presented in either the same language (e.g., L1 to L1) or in different languages (e.g., L1 to L2). The nonfluent bilinguals, as predicted by the model, were slower to make category matches when the target item was presented in the L1 and the category was presented in the L2 than when the reverse was true. However, the results showed that fluent bilinguals performed equally well whether the language of presentation matched or not. Therefore, the pattern of results for nonfluent bilinguals can be explained by the predictions of the Revised Hierarchical Model, i.e., that bilinguals should be slower when translating from the L1 to the L2. However, the model is less satisfactory in explaining the performance of fluent bilinguals, who were equally fast at matching L1 and L2 target items to category names, which would presumably require direct access to category membership information stored at the conceptual level.

In general, processing models of bilingual memory representations for language represent important theoretical advances for bilingual cognitive research and are useful in explaining a number of experimental findings in the literature. However, such models generally fall short of providing a complete account of the phenomena. In particular, these models do not attempt to address bilingual language processing beyond the most basic levels (i.e., word level), nor have they considered individual differences, such as age of L2 acquisition or sex. Indeed, de Groot (1995) has even suggested that a comprehensive model of bilingual memory may not be possible because memory structures are likely to vary enormously within bilinguals as a function of a variety of variables, including proficiency, word characteristics, learning strategies, L2 acquisition age, and language usage contexts. Similarly, Grosjean (1998) voiced concern about the predictive value of models that do not take into account the full range of “representational and cognitive complexity found within the individual bilingual” (Grosjean, 1998, p. 145).

Cognitive Research on Developmental Differences in L2 Learners

In addition to differences in language processing strategies related to differential language experience, age-related learning distinctions have also been hypothesized. It is generally accepted in the mainstream language lateralization literature that young children learn language differently than older children and adults (see review by Long, 1990). One idea has been that early first and second language learning will rely to a greater extent on discernment of the principles of linguistic structure for acceptable utterances in each language (autonomous view), whereas later second language learning will be influenced by existing knowledge of linguistic structures in the first language (interdependence view) (Bialystok & Hakuta, 1999; see also J. Paradis & Genesee, 1996).

A particularly intriguing analogy for differences in the cognitive strategies associated with the two hemispheres was put forth by Goldberg and Costa (1981), who suggested that "the left hemisphere [is] a collection of compartmentalized libraries and the right hemisphere [is] an eclectic master library" (p. 153). As such, the experienced language user might rely on the LH to a greater extent because it provides a well-rehearsed set of standard rules for accessing some language reference. A child just learning a language, however, has not yet mastered the rules governing the referencing of the language. In this case, the child may fare better (at least initially) by adopting a contextual or global (RH) strategy for locating and retrieving appropriate language information. Borrowing from this rationale, a late second language learner who has already developed a well-rehearsed system for cataloguing language might be expected to continue with this strategy to organize the second language. Conversely, a child learning two different language systems at once might find Gestalt-like RH strategies more useful for first identifying and then retrieving the language representation that is relevant to the situation.

Given that bilinguals differ in language acquisition history and in the particular languages they acquire, these variables could influence the cues used to perceive and organize words in the two languages. These strategy differences may in turn interact with presumed differences in hemispheric processing of language, and thus may alter the pattern of reliance on the preferred processing strategies of the two hemispheres in bilinguals relative to monolinguals, or in early vs. late bilinguals, especially where metalinguistic awareness is concerned (Vaid & Hall, 1991; Bialystok & Ryan, 1985).

Related research has suggested that older L2 learners have relatively advanced metalinguistic skills that make fundamental differences between the two languages more salient, thereby promoting greater use of problem solving (and perhaps LH-based) strategies to resolve conflicts in linguistic rules (see review by Long, 1990; see also Ullman, 2001). Younger learners, on the other hand, are thought to be better at perceiving similarities between the two languages, hence applying a more integrative (and perhaps RH-based) approach to language learning. Whereas models of bilingual memory representations for language do not specifically address language laterality or hemispheric processing differences, theories about preferential hemispheric processing strategies among certain groups of bilinguals could have bearing on the models. As noted in the previous section, experimental evidence has been reported for systematic differences in language performance between fluent and nonfluent bilinguals (e.g., Dufour & Kroll, 1995) and within bilinguals translating from the L1 to the L2 vs. from the L2 to the L1 (Kroll & Stewart, 1994; Heredia, 1996). When these findings are considered in light of theories about skill-related language processing differences in bilinguals (e.g., Ullman, 2001) and findings of hemispheric differences in semantic processing in monolinguals (e.g., Chiarello, Burgess, Richards, & Pollack, 1990, Chiarello & Richards, 1992), one may speculate on a relationship between language proficiency and lexical and/or semantic memory representations in bilinguals. For instance, declarative memory is thought to be regulated largely by the RH, whereas procedural memory is thought to be within the purview of the LH (Ullman, 2001; M. Paradis, 2000). Additionally, an increased role for the conscious and effortful processing of declarative memory, and thus for the RH, has been suggested for nonfluent language users, while greater reliance on the automated processes of procedural memory, and thus the LH, has been posited for fluent language users. Moreover, monolinguals (who can be considered fluent language users) show increased priming for semantically related words processed by the RH relative to the LH during lexical decision tasks (e.g., Chiarello et al., 1990). With these observations in mind, it may be that performance differences between fluent and nonfluent bilinguals during lexical decision tasks stem from a difference in hemispheric strategies rather than from differences in the ability to directly access the conceptual store from words in the second language. Another alternative is that differential ability to access the conceptual store from L1 and L2 lexical representations underlies functional hemispheric differences in language processing between fluent and nonfluent bilinguals. Future research may decide between these two possibilities, or perhaps show that they interact.

Cognitive Strategies Associated with Language Experience

There is an extensive literature focusing on cognitive repercussions associated with multiple language experience relative to single language experience (see review in Hamers & Blanc, 2000). Bilingualism is associated with increasing cognitive flexibility and divergent thinking and with an accelerated metalinguistic awareness (Bialystok, 2001). Less studied in this regard are possible cognitive differences associated with different forms of bilingual experience, in particular, with early, simultaneous exposure to two languages vs. later, successive exposure. The available research on this latter issue (e.g., Lambert & Moore, 1966; Lambert & Rawlings, 1969; Vaid, 1984a) supports the following generalization: When there is a choice, early bilinguals are more inclined to process words at a semantic level than are late bilinguals and show more influence of semantic/conceptual variables in word association and free recall tasks. They are also faster than late bilinguals in speeded semantic comparisons of words (Vaid, 1984a), and show a more field-independent cognitive style (Vaid & Lambert, 1979) than late bilinguals or monolinguals. Late bilinguals, in turn, appear to make preferential use of surface aspects of words, such as their acoustic features. Genesee et al. (1978) found that late bilinguals were faster than early bilinguals on an auditorily presented language recognition task, and interpreted this difference to reflect a surface-based strategy of identifying the language of the presented words. Similarly, Vaid (1984a) found that late bilinguals were faster than early bilinguals on a rhyme judgment task.

In light of these group differences in language processing strategy, it may not be surprising to expect an interaction of group differences with task-related differences in hemispheric processing of language. It is known from prior split-brain and normative studies with monolinguals that the left hemisphere is particularly involved in syntactic and phonetic aspects of language processing, whereas right hemisphere involvement is found on tasks emphasizing perceptual processing of words and pragmatic processing (Zaidel, 2001; Chiarello & Richards 1992). To the extent that laterality studies with bilinguals manipulate task demands, one may expect similar effects in bilinguals. Furthermore, task demands may interact with individual differences in bilingual processing strategies.

There is some support that laterality differences in bilinguals do reflect task differences and group by task interaction effects. For example, Vaid and Lambert (1979) tested hemispheric involvement in early and late bilinguals and monolingual controls using an auditory adaptation of the classic Stroop design. Spoken words were either congruent or incongruent with the pitch in which they were uttered (e.g., the word "high" spoken in a high vs. a low pitch). Participants were either to ignore meaning and identify pitch level, or ignore pitch and identify meaning. Whereas age-related differences in the cognitive strategies of monolinguals and bilinguals were found, these also interacted interestingly with participant sex. During the pitch discrimination task, monolingual men showed Stroop interference from word meaning only in the LH, whereas early bilingual men (L2 acquired before the age of five) and monolingual women experienced Stroop interference in both hemispheres, indicating that the processing of meaning took place in both hemispheres. Early bilingual women, on the other hand, showed Stroop effects only for the RH, pointing toward a right hemisphere proclivity for the processing of meaning. The authors interpreted these results to indicate that, in general, women and early bilingual men tended to employ a semantic processing strategy for verbal stimuli, even when the task only required phonetic processing.

In the meaning discrimination condition of Vaid and Lambert's experiment (1979), Stroop interference from pitch processing was expected in the left ear-RH route because the RH is thought to be slightly superior for pitch processing (see Klein, Zatorre, Milner, & Zhao, 2001; Kotik, 1984). In general, the prediction was upheld across the male groups. However, none of the female groups showed Stroop effects from pitch interference during the processing of meaning, suggesting that women may be better able than men to filter out pitch distractions from the meaning of words. Taken together, the auditory Stroop results suggested that the early onset of bilingualism coincides with a shift toward the RH for the processing of meaning relative to the monolingual pattern, and more so for bilingual women than men. Moreover, the results suggested that , in general, women are less lateralized than men across cognitive tasks that involve auditory processing of verbal material.

Another set of studies provided a more direct test of how language acquisition history may moderate functional asymmetries for language organization in bilinguals (Vaid, 1984a). Lateralized performance was measured in three experiments with both early (L2 acquired before age six) and late (L2 acquired after age 12) bilinguals. Participants were to make speeded same-different judgments on word pairs varying in orthographic similarity (word form), phonetic similarity (rhyme), or semantic similarity (semantic category membership, and synonymity).

The results showed that tasks involving phonetic processing showed the greatest LH effects whereas those that involved visual or semantic processing showed the weakest LH effects. Moreover, semantic judgments took longer than rhyme or orthographic ones overall, and recall was generally superior for words processed semantically suggesting that deeper processing had taken place across groups for semantic vs. surface word features. Consistent with expectations about group differences in processing mode, speed and recall effects for semantically processed words were more pronounced for early relative to late bilinguals, and more so in the RH than the LH. Vaid (1984a) suggested that early bilinguals' apparent preference for processing words semantically might have been fostered by an earlier realization of the arbitrariness of sound/meaning relationships and thus a focusing on content over form. In contrast, late bilinguals' greater use of surface level word features, Vaid suggested, may have been a byproduct of a strategy for monitoring words to decide on their language status.

While the studies cited thus far have considered fluent bilinguals, several other studies in the cognitive and laterality literature with bilinguals have examined language proficiency-related effects. A. Green (1986) used tachistocopic viewing to compare performance on word-level object naming of concrete nouns vs. sentence-level picture description in three groups of bilingual men varying in L2 proficiency, and all of whom had acquired or were acquiring the L2 during puberty or later. Whereas no main effect or interactions were uncovered for task type, the findings showed that adults in the initial stages of L2 acquisition showed less LH dominance for the L2 as compared to the L1. Conversely, fluent bilingual men were more bilaterally activated for the L1 than nonfluent bilingual men. Green further reported that variability in lateralization within the three fluency groups (i.e., nonfluent, moderate, fluent) increased exponentially with proficiency in the L2. These results suggest that L2 fluency may have predictive value in terms of overall laterality in bilinguals, but may not be a good indicator of task related differences in late bilinguals, at least for word vs. sentence level speech production.

de Groot, Borgwaldt, Bos, and van den Eijnden (2002) reported that bilinguals showed no difference in response times for lexical decision and word naming tasks in their less fluent L2, whereas they were significantly slower at lexical decision than word naming in their native language (the typical pattern found for native speakers of a language). The authors suggested that the anomalous pattern of results was a product of a longer processing time to prepare the vocalized naming response in L2, the less fluent language.

Numerous recent neuroimaging studies have also reported a relationship between language skill and patterns of brain activity during language tasks. For instance, one such study reported that moderately fluent late bilinguals (L2 acquired after age seven) showed a considerable decrease in activation during L2 relative to L1 processing, with some brain areas that had been active during the latter showing no measurable activity during the former (Perani et al., 1996). Contrasting results were reported in a separate study with highly fluent late bilinguals (Klein, Milner, Zatorre, Zhao, & Nikelski, 1999). Specifically, this study found no activation differences during verbal tasks in either language.

Another line of research on cognitive strategies for language recognition and production focuses on explicating the mechanisms bilinguals may use to handle competition between the two languages as a function of their usage frequency. One model proposes that language selection is governed by an inhibitory control mechanism (D. Green, 1986). In this model, it is supposed that, if a bilingual uses both languages in daily life, then both languages maintain "near-threshold" levels of activation, even when only one is selected for immediate use. Consequently, the unselected language must be inhibited to avoid interference errors, and this inhibition is thought to make greater demands on cognitive resources as a function of how frequently the unselected language is typically used. Therefore, Green suggested that bilinguals who use both languages with roughly equal frequency should have fewer cognitive resources available during verbal tasks than bilinguals for whom the L2 is clearly less used (and thus requires less active inhibition). That is, increased difficulty of a cognitive task will more negatively affect the performance of a frequent L2 user because available cognitive resources are being depleted by effortful inhibition of the L2.

Studies involving switching across languages to name pictures or numerals provide some evidence in support of the inhibitory control model (D. Green, 1986). In general, such studies show that switching from the L2 to the L1 produces a greater processing cost (e.g., slower response times) than the reverse (e.g., Meuter & Allport, 1999). This pattern of results has been interpreted to indicate that the increased inhibition required to suppress the presumably dominant L1 during L2 trials is harder to overcome in subsequent L1 trials, resulting in a greater processing cost of switching back to the L1.

Overall, there is little evidence concerning the relative contributions of lexical activation vs. inhibitory control in bilingual language processing. However, Gollan and Kroll (2001) have suggested that future research may begin to tease apart the roles of inhibitory vs. activation mechanisms by manipulating task demands that differentially affect language representation (e.g., language switching tasks) and language control (e.g., translation tasks), and then evaluating whether performance reflects interference or facilitation.

From Lesion Data to Bilingual Neurocognitive Perspectives

One reason to suspect that bilingual language representation may differ from the canonical LH pattern found in monolinguals comes from numerous aphasiological case studies of bilingual patients with brain damage that have reported nonparallel (i.e., rate differences) patterns of postmorbid recovery of languages (see Abutalebi, Cappa, & Perani, 2001; Vaid, 2002a; Vaid & Hull, 2002; Fabbro, 2001; M. Paradis, 2001). For example, some bilingual aphasic patients may lose the ability to communicate in one language but retain communicative skills in another. Other patients may retain full use of one language while progressively recovering the other. Especially baffling cases of language recovery include bilingual aphasics who can communicate in the L1 (but not the L2) one day, and then display the opposite pattern the following day!

Another relevant classical source of evidence on bilingual language representation is the higher incidence of crossed aphasia (language deficits following damage to the right hemisphere). In monolinguals, the estimated incidence is very low, i.e., 2-4%. In bilinguals, though, it is higher. For example, in a survey of 31 bilingual aphasics, Albert and Obler (1978) reported that 80% of the patients with right hemisphere damage showed nonparallel language recovery, but only 42% of those who suffered LH damage showed a similar pattern. A comprehensive review of the bilingual aphasia literature was conducted by Galloway (1982), who compared the incidence of crossed aphasia in 88 bilingual and 340 monolingual patients for whom information about lesion side and handedness were available. She found that bilingual patients experienced language disruption following RH lesions three times more often (15%) than monolinguals with a similar pattern of damage (4%).

It has been suggested that sampling bias may have played a role in the reported numbers of monolingual and bilingual crossed aphasics, with clinical cases representing selected rather than random samples (M. Paradis, 1977). To minimize the potential for sampling bias, a more recent study assessed the incidence of crossed aphasia in all stroke patients for whom language background was available and who did not demonstrate dementia (Karanth & Rangamani, 1988; see also Vaid, 2002a). In all, 31 cases of monolingual and bilingual patients with right hemisphere lesions were identified at the National Institute of Mental Health and Neurosciences in Bangalore, India. The study found no cases of crossed aphasia in the sample of 7 monolingual patients, while the 24 bilingual patients showed a crossed aphasia rate of 25%. Data such as these lend support to the idea that language representation of bilinguals may be more symmetrically organized than that of monolinguals, possibly through the recruitment of relatively more right hemisphere structures (e.g., Albert & Obler, 1978; Genesee, 1982).

The lesion data provide some general guidelines for laterality research, but there are limitations to the explanatory value of such data when addressing neurologically healthy individuals. For instance, they leave unclear whether specific language deficits are the result of trauma to a specialized brain component at the lesion site or if the damaged area is simply part of a larger neural network that mediates a given component of language (see Vaid & Hull, 2002; Abutalebi et al., 2001). Nevertheless, studies on the effects of brain damage on linguistic function are of heuristic value, providing specific bases for pursuing questions about how language may be differentially represented among individuals with differing language acquisition histories.

Recent theories have elaborated on explanations for differences in hemispheric preference for language processing in brain-intact bilinguals. One theory has proposed a shift in lateralization as cognitive processes mature from an initial reliance on context-sensitive and holistic RH-mediated strategies in younger children to a subsequent reliance on LH-mediated strategies that emphasize active analytic processing and computational grammar (Johnson & Newport, 1989; Kersten & Earles, 2001; see also Ben-Zeev, 1977). Another theoretical account of hemispheric functional specialization for language posits variation in the contribution of procedural and declarative memory systems as a function of language proficiency (Ullman, 2001; M. Paradis, 2000). This view proposes that the LH is specialized for the relatively automated processing associated with well-learned and routinized codes (such as the computational rules of syntax) and thus underlies the functions of procedural memory. The declarative memory system, on the other hand, is thought to rely to a greater extent on the RH, which is considered to be relatively superior for associative/contextual binding of information, conscious control, and pragmatic language cues. On the basis of this account, well-learned native languages and fluent second languages should depend more heavily on the relatively automated procedural functions of the left hemisphere. Conversely, beginning L1 and less fluent L2 learners might be forced to employ greater conscious control over language processing and to depend more on contextual communication cues, hence relying to a greater extent on the declarative memory functions subserved by the right hemisphere.

Experimental evidence for laterality changes as a function of language proficiency has been reported by some researchers. In a study by Kotik (1984), ninety-one late learners of Russian as a second language who varied in terms of L2 skill were compared on word recall in a dichotic listening task. Kotik found that the errors made by nonfluent L2 users were qualitatively different from those made by proficient users. Specifically, nonfluent bilinguals had difficulty discriminating phonologically similar nonsense words from real Russian words (acoustic/prosodic errors), whereas proficient users occasionally substituted phonologically and semantically related real words for other real words (semantic errors). Moreover, the mistakes made by skilled L2 users were similar to those typically found in native Russian speakers. Importantly, the nonfluent group showed significantly more RH involvement for the L2 (and also relative to their performance in the L1) than the matched fluent group, who displayed LH dominance for both languages.

Hemispheric strategy differences during sentence-level processing and the accessing of word meaning have also been extensively studied with monolingual populations. Researchers who have studied sentence-level processing have suggested that the two hemispheres contribute differential strategies for processing meaning. The RH is thought to be involved in making connections between individual lexical items in a sentence, whereas the creation of actual sentence meaning is thought to be carried out in the LH through the analysis of grammatical and syntactic cues (for a review, see Faust, 1998). Chiarello, Liu, and Faust (2001), however, found that that both hemispheres were equally sensitive to sentence-final anomalous words and suggested that both hemispheres are involved in processing sentence-level meaning. In a separate study, Liu, Chiarello, and Quan (1999) showed that both hemispheres benefited from grammatical information contained in number agreement within noun phrases. Taken together, these results have prompted Chiarello and her colleagues to suggest that both hemispheres participate in accessing individual word meanings and at least certain grammatical mechanisms and, thus, that both hemispheres may be involved in comprehending sentence meaning, albeit in distinctly different ways.

At the word-level, a number of experiments have shown that the RH may be instrumental in actively maintaining an array of close and distant meaning choices during word processing, whereas the LH may be preferentially involved in selecting only closely related word meanings. For instance, Chiarello et al. (1990) used a visual half-field paradigm to present a semantic priming, lexical decision task for three types of semantically related prime-target pairs. Increased priming was detected when similar-only pairs (e.g., “deer-pony”) were processed by the RH relative to the LH, no priming was found in either hemisphere for associated-only pairs (e.g., “bee-honey”), and equal priming was obtained in both hemispheres for similar+associated pairs (e.g., “doctor-nurse”). The authors inferred from the pattern of results that the RH was preferentially involved in automatic access to semantic category membership (i.e., the similar-only pairs) by virtue of diffuse spreading activation from the prime word to a host of potential target words that were semantically related. In contrast, pairs processed in the LH might have been subject to a rapid selection strategy for the most likely match while other potential candidates were suppressed. That is, semantic relatedness alone was insufficient to prime the targets when the pairs were processed in the LH, but benefits were obtained when the target was highly related to the prime, both semantically and associatively.

In a later study, Chiarello and Richards (1992) used a procedure identical to Chiarello et al. (1990) except that this time the prime-target pairs were weak associates, and the primes varied on degree of exemplar dominance (e.g., “robin-crow” was a high dominant pair, and “duck-crow” was low dominant). The results showed that priming was obtained only for prime-target pairs presented in the left visual field (i.e., RH), and the effect was consistent regardless of the dominance of the prime. Chiarello and Richards interpreted the finding as further support for the idea that the RH activates and maintains a wide range of related meanings during word recognition tasks relative to the LH.

Taken together, the theoretical approaches and the clinical and experimental findings with monolinguals and bilinguals as discussed above provide a rationale for a separation in hemispheric specialization for certain types of language processing. In sum, the LH is thought to be superior for modality-specific language processing, such as speech sounds (e.g., Molfese, 1977), for rule-based, sequential/analytical processing (e.g., Faust & Chiarello, 1998), for storing and processing routinized codes, as in grammatical knowledge (Ullman, 2001; Bentin, 1981), and for rapid selection of single word meaning (Chiarello et al. 1990). The RH may be described as being preferentially involved with superficial acoustic/phonetic processing, such as pitch (Vaid & Lambert, 1979; Kotik, 1984; Hickok, 2001), Gestalt-like or holistic synthesis of information, such as combining contextual cues with words (Levy-Agresti & Sperry, 1968; Witelson, 1977; Chiarello et al., 1990), greater flexibility in processing language stimuli (Zaidel, 2001) and for making available a wide range of choices in semantically related word meanings (Chiarello et al. 1990; Chiarello & Richards, 1992).

In sum, accumulating bilingual laterality research indicates that differences in hemispheric specialization and/or functional organization for language may emerge as a result of differences in language acquisition history (see reviews by Vaid & Hall, 1991; Hull & Vaid, forthcoming; Zatorre, 1989; Long, 1990). Based largely on the lesion data, attempts to explain the effects of language experience on laterality have predicted that certain groups of bilinguals will employ more right hemisphere strategies or structures than other groups (e.g., Genesee, 1982; Galloway, 1983; Obler et al., 1982; Silverberg, Bentin, Gaziel, Obler, & Albert, 1979).

Methodological Challenges in the Bilingual Laterality Literature

Given that over 100 behavioral bilingual laterality studies have been conducted, and some 40 additional ones exist that have used hemodynamic or electrophysiological measures, a potential obstacle in summarizing the bilingual laterality findings is the sheer size and complexity of the literature. Another hurdle for identifying a consensus across findings in existing studies of bilingual laterality is that the original studies inconsistently defined early vs. late second language acquisition. Some researchers operationalized the dividing point around entry into grade school (approximately six years of age), others around puberty (approximately 12 years of age), and still others at different times in the lifespan (see Hall & Lambert, 1988). Given the enormous amount of language experience and learning that takes place between the sixth and twelfth years of age, one might expect to find substantial variation in the mean fluency of the two age groups on language tasks. An empirical study on bilingual laterality that examines either age of L2 acquisition or fluency without considering the other variable cannot make sound conclusions about which moderator is responsible for any differences that may be detected in language lateralization within bilingual subgroups. That is, conclusions from such studies with respect to the neural consequences of age or proficiency of second language acquisition must be viewed with caution, as the results may reflect the influence of either fluency or acquisition age – or an interaction of the two – as explanatory moderators of hemispheric specialization for language. Such methodological inconsistencies have likely contributed to the diversity of results across studies.

Aside from the above sources of variability, studies also vary in methodological rigor. Many of the early studies did not systematically screen bilinguals on proficiency or other relevant parameters (e.g., L2 acquisition age). Others did not match stimuli across the two languages in terms of frequency, length, or other relevant criteria. Still others did not use appropriate statistical analyses (see Obler et al., 1982). The present research synthesis attempted to disentangle these potential confounds by coding the study data into different levels of theoretically grounded moderating variables of bilingual laterality.

PRIOR META-ANALYSES OF BILINGUAL LATERALITY

The present state of the bilingual laterality literature suggests that there is something fundamentally different about the cerebral organization of language among bilingual subgroups, but exactly how such differences are manifested remains unclear. In other words, if cerebral circuitry and/or functional organization adapt to accommodate language systems over and above the native one, do the particular characteristics of an individual's language learning experience influence such neural or functional adaptation? Although several qualitative reviews of the bilingual laterality literature have appeared in the last twenty years (e.g., Vaid, 2002a; Galloway, 1983; Vaid, 1983; Vaid & Genesee, 1980; Zatorre, 1989), only two previous meta-analyses have been conducted (Hall & Vaid, 1990; Hull & Vaid, 2002).

In the earlier meta-analysis, Hall and Vaid (1990) assessed the results of 59 language laterality studies. They reported an overall left hemisphere advantage for the first language across both monolingual and bilingual groups, though early bilinguals (L2 acquire by age six) were less lateralized as compared to late bilinguals (L2 acquired after age 10). Moreover, the authors noted that differences between the two bilingual groups seemed to be particularly evident when different strategies could have been employed to complete the task. These findings led Hall and Vaid (1990) to conclude that only certain subgroups of bilinguals differed in language lateralization from monolinguals and other bilinguals. In a later summary of their meta-analysis, Vaid and Hall (1991) cautioned that inadequate operationalization of some hypotheses, such as the stage hypothesis, could have contributed to the lack of support obtained for those hypotheses.

A more recent meta-analysis of the bilingual laterality literature was conducted by Hull and Vaid (2002; see also Hull and Vaid, forthcoming) to address specific questions concerning differences in language lateralization between users of one vs. multiple languages, as well as to investigate whether differences in language lateralization may arise in part from the particular experimental paradigm used to infer laterality. The Hull and Vaid meta-analysis differed from the previous one in certain important respects: It controlled for language status and language-specific effects by using only comparisons of bilinguals tested in the first language against monolinguals in the same language. Within the subset of bilinguals included in their study, Hull and Vaid also examined variations in language lateralization arising from differing second language (L2) fluency and/or age of L2 acquisition histories. Twenty-three empirical studies of language lateralization that directly compared monolinguals and bilinguals on the same first language were assessed. This condition was expected to minimize any language-specific effects that may have influenced conclusions concerning differential laterality as a function of language experience (i.e., knowing one vs. two languages).

The overall results showed that monolinguals and bilinguals were differentially lateralized for language, with bilinguals as a group showing less cerebral asymmetry than monolinguals during verbal tasks. However, this finding was qualified by a three-way interaction of bilingual language experience, L2 acquisition age, and L2 fluency. Specifically, early fluent bilinguals (both languages acquired prior to age six, and both being considered first languages) were bilaterally activated for all language tasks and paradigms, whereas late fluent bilinguals were more left hemisphere dominant than early bilinguals for the first language. Moreover, Hull and Vaid noted that the partitioning of the bilingual sample by these three moderators resulted in all of the variance within each group being explained by sampling error. However, to address suggestions in the literature, direct comparisons were made to assess sex-related and paradigm differences. The results indicated that monolingual men were the most LH lateralized, followed by, in descending order, monolingual women, bilingual women, and bilingual men. Moreover, the dichotic listening paradigm elicited the greatest LH participation across language groups, dual task studies were somewhat less LH oriented, and tachistoscopic viewing paradigms recruited the less LH involvement.

As has been discussed in the present paper, several hypotheses in the bilingual laterality literature have predicted greater right hemisphere involvement for in one or both languages for at least some groups of bilinguals, relative to monolinguals (see

Genesee et al., 1978; Genesee, 1982; Galloway, 1983; Vaid & Lambert, 1980; Obler, 1981). What has not been clear in these hypotheses is whether more right hemisphere involvement was expected to be commensurate with less left hemisphere activity. To address this issue, Hull and Vaid (2002) conducted direct comparisons of effect sizes drawn from left hemisphere activation during language tasks performed by monolinguals, early bilinguals, and late bilinguals. The results revealed no group differences in effect sizes of LH involvement during language processing.

From the results of their meta-analysis of monolingual vs. bilingual language lateralization studies, Hull and Vaid (2002) concluded that functional brain lateralization for one or both languages of early bilinguals differed from that of monolinguals and late bilinguals overall. However, they noted that whether the variations reflected group differences in language processing strategies or were derived from neurologically or physiologically distinct bases could not be determined. The authors further concluded that the relatively greater amount of RH activation uncovered for early bilinguals was not coincidental with less LH involvement, hence the typically observed LH participation in language processing appears to be similar across groups with varying language acquisition histories. However, early acquisition of two languages appears to recruit increased participation of the RH for language processing relative to either monolinguals or late bilinguals.

Other observations from Hull and Vaid (2002) included the suggestion that the acquisition of multiple languages appeared to have a greater impact on the functional brain organization of language for men relative to women, though, again, the reasons for such an effect were not discernable. A final observation was that, while behavioral paradigms for inferring the cerebral lateralization of language appeared to be inconsistent in terms of the degree of cerebral asymmetry they elicited, the general patterns of variation were consistent across language experience groups. Hull and Vaid suggested that this result provided a measure of confidence that any paradigm-specific effects that did not involve language processing per se (e.g., general auditory processing demands) were operating in the same way across studies and across participant groups.

THE PRESENT RESEARCH

As a result of theoretical, methodological, and experimental variations across studies of language lateralization, it has been difficult to summarize and interpret this literature. The challenges involved in establishing clear results from an inconsistent pattern of findings are particularly suited to the techniques of meta-analysis (see Rosenthal, 1994). That is, quantitative meta-analysis is designed to detect underlying patterns across large quantities of disparate data samples, thus minimizing the influences of researcher bias, paradigm bias, procedural bias, and reliance upon particular methodologies, any of which may obscure real effects described by the data (Rosenthal & DiMatteo, 2001). Furthermore, meta-analysis retains aspects of the narrative review, such as comparing and contrasting a variety of studies in a literature, while adding a quantitative component that allows one to estimate the size and direction of relationships between individual independent and dependent variables. This latter feature is especially helpful in the refinement of theories that underlie primary research.

The motivation for the present comprehensive meta-analytic review was in part a response to numerous observations regarding the inconsistent directions of bilingual laterality findings reported in the literature and a few outright challenges to the value of bilingual laterality research in general (e.g., M. Paradis, 1992). In addition, the present quantitative synthesis was warranted by the encouragingly similar findings for differential lateralization among bilingual subgroups in the two previous meta-analyses of subsets of this literature (Hall & Vaid, 1990; Hull & Vaid, 2002). The present meta-analysis built from the previous one in two primary ways. First, it included all available behavioral laterality studies to date that were carried out with bilingual participants (i.e., including those without monolingual comparison groups). Second, it evaluated the effects of a number of potential moderators, some of which had not been quantitatively reviewed previously (see below). The moderators tested in the present research were L2 acquisition age, L2 fluency, participant sex, experimental paradigm, verbal task demands, context of language use, and relatedness of linguistic structure. In addition, the effects of English as the second language and publication status of studies were evaluated.

Two syntheses were conducted to investigate functional cerebral lateralization for language in bilinguals. The first of these evaluated study results concerning first languages, and the second assessed second language results. First and second languages were analyzed separately for theoretical and statistical reasons. Earlier in this paper, we reviewed evidence from the aphasia literature that provides a compelling argument that the two languages of bilinguals may be functionally distinct in the brain (e.g., Fabbro, 2001). Furthermore, if one accepts that most bilinguals will not be perfectly balanced in terms of L1 and L2 competencies (e.g., Grosjean, 1998), processing differences might be expected between the two languages. Experimental evidence has been presented that age-related and skill-related processing differences may give rise to different functional organization of the L1 and L2 depending on the age at which each was acquired or the skill-level in each (e.g., A. Green, 1986). Moreover, other experimental evidence for differences in L1 vs. L2 processing demands have been pointed out in terms of preparing vocalized output in bilinguals who are not completely balanced in the two languages (de Groot et al., 2002). Other researchers have also suggested that a less fluent L2 may be processed differently from a fluent L1 (e.g., Hardyck, 1980).

From a statistical standpoint, it makes further sense to meta-analyze first and second languages separately. That is, the present research relies on the calculation of fixed-effect categorical models based on d scores from multiple levels of moderating variables (described in the method section), and the interpretation of such models is most appropriate when the ds are statistically independent. Collapsing data for first and second languages would result in nonindependence of the vast majority of data points, because over 90% of the studies included in the present sample tested the same bilinguals on both languages. In sum, sufficient rationale exists to separately assess the overall pattern of results in the bilingual laterality literature for first and second languages.

As noted above, sufficient evidence has been reported in the bilingual laterality literature to warrant the investigation of L2 acquisition age and L2 fluency as moderating variables. In what follows, other variables that were coded and analyzed in the present research are briefly discussed.

Sex-Related Differences

One much-studied line of research has supposed that men and women differ in brain functional laterality for language processing. Evidence for sex-related differences in verbal and non-verbal lateralized performance was reported in a recent meta-analysis that included both monolingual and bilingual men and women (Voyer, 1996). The study also assessed gender differences for stimuli presented in three separate dimensions, namely, the visual, auditory, and tactile modalities. The research synthesized the results of 266 published studies that specifically evaluated sex as an independent variable in verbal and nonverbal functional asymmetries. The results showed that sex-related laterality effects were most prominent for verbal abilities in the visual and auditory modalities, and in particular for word naming tasks. In general, men were found to be more LH lateralized than women for verbal tasks.

It is worth noting that the vast majority of the sample in Voyer's (1996) meta-analysis involved monolingual language users. Therefore, caution is in order when generalizing the results to the bilingual population. Furthermore, only published works were assessed, and within those, a value of zero was assigned in cases where the study authors had reported a nonsignificant effect without further data from which effect sizes could be calculated. Though assigning zero values in such cases is an acceptable option in the meta-analytic technique, it has the potential to artificially deflate the sample variance, which, in turn, might artificially narrow the confidence intervals and render group differences significant when they might not otherwise have been had the true variance been included. On the other hand, the practice allowed the synthesis of results from a very large number of studies, conferring greater confidence that the findings for sex-related differences in functional asymmetries for language have theoretical plausibility. Voyer's work remains among the most valuable recent contributions to the literature on gender differences for brain functional asymmetries.

Whereas the meta-analysis of sex-related differences in language lateralization for the sample with mixed language experience showed clear and reliable sex differences (Voyer, 1996), experimental studies that assessed sex differences within the bilingual population have yielded mixed results. For example, Shanon (1982) reported results from a visual field asymmetry paradigm showing that bilingual men showed greater RH involvement for single word processing relative to bilingual women. Similar results were reported by Mägiste (1989), who used conjugate lateral eye-movements during sentence production to infer hemispheric involvement in verbal processing. Specifically, Mägiste reported that bilingual men showed greater RH involvement than either monolinguals or bilingual women, with the latter group showing bilateral symmetry during verbal processing. Conversely, Persinger, Chellew-Belanger, and Tiller (2002) conducted a dichotic listening task that revealed greater LH involvement for bilingual men relative to women during single word processing. Yet another pattern of results was reported from a dual task study by Green, Schweda-Nicholson, Vaid, White, and Steiner (1990), who found no differences in language lateralization between bilingual men and women during sentence production.

While it is possible that the inconsistent pattern of results concerning sex differences across bilingual laterality studies may derive from differences in task demands (e.g., visual vs. auditory) or linguistic components (e.g., word vs. sentence level) or paradigm (e.g., visual hemifield vs. dichotic listening), findings of sex differences in lateralized performance for language across the different measurements from an array of experimental studies provides adequate justification to synthesize the results across the larger body of bilingual laterality studies.

Differences in Processing Demands and Levels of Language Tested

One persistent challenge in summarizing the bilingual laterality literature is the sheer number of tasks used to test a variety of language features. While valid inferences regarding the nature of language processing require tests of the entire range of language components (e.g., letters, syllables, words, phrases, sentences), the diversity presents a challenge when one tries to summarize experimental findings across the literature. Additionally, tasks ranging from free word recall to Stroop tests to translation and more have characterized hemispheric lateralization studies. Therefore, it may be unwarranted to infer that experimental findings should be similar when the data were derived from a variety of tasks and/or levels of language. For instance, we have seen that results from word level lexical decision tasks might differ in hemispheric participation as a function of task complexity (e.g., Vaid & Lambert, 1979) or whether the words are semantically related (e.g., Chiarello et al., 1990). Brain activation during sentence level processing has also been shown to differ according to complexity, with complex sentences that contain object relative clauses, such as “The reporter that the senator attacked admitted the error” tending to recruit increased and bilateral frontal activation relative to syntactically simple sentences that contain only active clauses, such as “The reporter attacked the senator and admitted the error” (Just, Carpenter, Keller, Eddy, & Thulborn, 1996). Moreover, evidence for increased RH involvement has been shown when sentences contained semantically rich word classes, including high imageable nouns, such as dog or apple, but the same words produced an LH processing advantage when they appeared in isolation (Chiarello, Liu, Shears, & Kacinik, 2002; see also Zatorre, 1989).

In addition to word level vs. sentence level factors, differences in hemispheric participation have been suggested for the processing of specific word features. For instance, the processing of syntactic features of words is thought to entail greater LH participation, perhaps as a function of implicit or procedural memory, at least in fluent language users. The processing of semantic features, however, may involve more bilateral activation and may also rely to a greater extent on the RH-based declarative memory system (see Faust & Chiarello, 1998; Ullman, 2001). Moreover, semantic features are thought to elicit a deeper level of processing, and thus a different processing strategy relative to either orthographic or phonetic word features (e.g., Vaid, 1984a). Yet another facet of semantic processing demands may be implicated in word priming tasks that involve category matching, as recent evidence has indicated that semantic priming of words may be automatic, at least where the RH is involved (e.g., Chiarello & Richardson, 1992). As a result, studies that manipulate semantic vs. orthographic features during word processing may also be comparing an automatic vs. a strategic process respectively, and thus findings of differential hemispheric participation might be particularly expected.

Finally, research with monolinguals has consistently uncovered a left hemisphere effect for speech production (e.g., Holowka, & Pettito, 2002; Molfese, 1977; see also Moscovitch, 1977). In addition, a number of neuroimaging studies have shown that speech perception is bilaterally mediated (see reviews by Price, 1998; Vaid & Hull, 2002), whereas speech production appears to be preferentially processed in the LH (e.g., Hickock, 2001). Bilinguals who were fluent in the L2 (but less so than in the L1) showed the typical pattern of significantly slower production of nonvocalized lexical decision responses than vocalized word naming responses in their native language, whereas they showed no difference in response times for the two tasks when they were performed in the L2, which the authors concluded was a result of increased time to prepare the vocalized response in L2. Taken together, these findings suggest that it is reasonable to investigate whether vocalized responses during language laterality tasks create a different pattern of cerebral activation relative to nonvocalized responses.

In sum, it is clear that language processing may take many forms, and any attempt to evaluate the landscape of results from studies of brain functional organization for language must consider how the different levels of language may interact with cognitive demands and laterality. Given just the brief summaries presented here that describe a mere subset of the possible levels into which linguistic processing demands could be divided, one can easily see how attempts to summarize laterality effects without taking the language components that were tested into account could result in conclusions of little or no effect. One might even conclude that the literature is so rife with contradictory findings that it has become a “monster” (M. Paradis, 1992). Notably, finer divisions of language than those described are certainly possible (e.g., concreteness-abstractness, syntactic categories, word frequency), but a preliminary review of the bilingual laterality literature indicated that these were the most frequently studied language features. Consequently, in the interest of obtaining cell sizes adequate to produce reliable meta-analytic results, the following seven levels were coded: 1) vocalized responses to single word stimuli, 2) nonvocalized responses to single word stimuli, word pair judgments on 3) phonetic, 4) orthographic, 5) semantic, or 6) syntactic similarity, and 7) nonvocalized responses to sentence-level stimuli.

Differences in the Linguistic Distance Between L1 and L2

The linguistic distance between the two languages of bilinguals, i.e., the degree of overlapping language structure, has been discussed as a potential moderator of language laterality (e.g., Fabbro, Gran, & Bava, 1989; Obler et al., 1982; Tan et al., 2003). Presumably, languages that are structurally very dissimilar, such as Chinese and English, should show greater differences in language laterality than that structurally related languages, such as Spanish and French. Processing differences for structurally distant languages have been suggested to arise based on such features as orthographies (e.g., different types and/or directions of script), phonetic composition (e.g., tonal Chinese vs. syllabic English), and the differing importance of prosodic cues (see Obler et al., 1982; Klein et al., 2001). Based on such inherent differences across languages, linguists have developed “language trees” (widely available in textbooks and encyclopedias) to organize the world’s languages into divisions based on genetic similarity, i.e., derivation from a common root language. The present research made use of such information to devise three categories of relatedness for first and second languages, namely, related (same branch, same family), semi-related (different branch, same family), and unrelated (different families).

English as a Second Language

Given that 58% of the second languages for which bilingual laterality data were reported included English as the L2, it seemed reasonable to examine whether English would differ in terms of functional organization relative to the remainder of second languages that were tested. That is, it was reasoned that if language-specific factors matter to functional language organization, then the present English-heavy sample could disproportionately influence the meta-analytic results in the direction of any effects that might be a product of the specific structural properties of English. Unfortunately, the diversity of other second languages that were included in the present sample made it impractical to examine each of the other languages separately, as the resulting cell sizes would generally have been too small to yield reliable results, and none of the other second languages represented a disproportionate percentage of the sample. Therefore, L2 data in the present meta-analysis were coded and analyzed in terms of whether English or "other" was the second language.

Differences in Language Environment

Whereas current hierarchical models of bilingual memory representations for language assume that there will always be functional language asymmetry between the L1 and L2 as a result of the preferentially strong pathways from the L1 lexicon to the conceptual store, some of theorists have postulated that the environmental context in which first and second languages are used may alter this pattern. As we have seen, Heredia (1996) has proposed that prolonged dominance of use of the L2 relative to the L1 may actually reverse the strength of lexical-conceptual connections, thereby modifying functional language asymmetries. Experimental evidence for the influence of environment is found in a recent study by Evans, Workman, Meyer, & Crowley (2002), who reported that L2 acquisition age interacted with language environment in late bilinguals living in a predominantly L1 environment as compared to other early and late bilinguals living in a fairly balanced L1-L2 environment. Specifically, the authors noted increased RH involvement during language processing only in bilinguals who had acquired the L2 in a single language environment after the age of about six. Grosjean (1998) has also noted that language competency may be altered by prolonged environmental demands for preferential usage of one or the other language. Globally, the environmental contexts in which a bilingual may use the two languages vary widely (e.g., a predominantly single-language environment in the United States vs. a predominantly dual-language environment in Canada).

The present research considered three categories of environmental context to code each of a bilingual's two languages, namely, submerged, integrated, and limited, as potential moderators of functional language laterality. The submerged category was intended to capture contexts in which the bilingual lived in a country where the coded language was the dominant one (e.g., living in Spain when Spanish was the L2), and thus the individual was "submerged" in the language on a daily basis. The integrated level was meant to reflect situations in which the bilingual was likely to be exposed to both languages daily (e.g., in Canada). Finally, the limited category was created to describe environments where a bilingual's use of one of his/her languages was likely to be used only in specific and relatively restricted conditions (e.g., a Korean foreign national attending graduate school in the United States). It must be noted that levels of environmental context were fairly broad, and the assumption that the bulk of bilinguals would fall into one of these categories may not be warranted. Nevertheless, they served as an attempt to describe and investigate the qualities of different social contexts in which bilinguals might use language.

Differences in Experimental Approaches

Before discussing the behavioral language laterality paradigms evaluated in the present research, a brief description is offered of several nonbehavioral techniques that have more recently been increasingly utilized for investigating language-related brain activity, namely, electroencephalographic (EEG) recording, event related brain potentials (ERPs), magnetic source imaging, positron emission tomography (PET), and functional magnetic resonance imaging (fMRI). Unfortunately, very few of these have been designed to permit comparisons of overall LH vs. RH activation. Indeed, the vast majority of the nonbehavioral studies were not designed to address laterality per se, but focused instead on intrahemispheric comparisons of language performance in bilinguals, e.g., in Broca's area of the left hemisphere (see review by Vaid & Hull, 2002). Consequently, when laterality differences were discussed at all, they were generall presented in only a qualitative manner. As a result, only six (or 15% of the total sample of nonbehavioral studies) provided laterality data relevant to the meta-analysis.

An additional challenge to synthesizing the results of nonbehavioral studies was that language laterality effect sizes from these studies were generally much larger than those of the standard laterality paradigms, hence disproportionately increasing the observed variance and possibly distorting the means. Consequently, the inclusion of such studies in the present research synthesis would likely affect our conclusions about data derived from the classic behavioral techniques. Therefore, it is believed that it may be warranted to exclude the nonbehavioral studies from the present research to permit a clearer set of conclusions about the bulk of the data that derive from the standard behavioral paradigms. Moreover, even if the data derived from nonbehavioral studies had been well in line with the behavioral ones, it would not have been justifiable to extrapolate to the larger set of nonbehavioral studies conducted with bilinguals, as these could not be included in the present meta-analysis for reasons of insufficient laterality data. It is suggested instead that an evenhanded solution may be to examine nonbehavioral bilingual laterality studies as a separate body, once there are sufficient numbers of such studies to permit the relevant hemispheric comparisons.

In light of the above rationale, the present research included bilingual laterality studies that used visual preference (V), dichotic listening (DL), and verbal/manual interference or dual task (DL) paradigms to assess hemispheric involvment. These methods have typically relied on different response measures (reaction time, accuracy, and interference size, respectively). Moreover, the language tasks that have been employed in these paradigms may add a further layer of variability in effect sizes, as dichotic listening studies typically use words that are to be recalled while visual half-field studies most often use word naming or speeded word judgments of different sorts for stimuli varying on visual, phonetic, semantic or syntactic dimensions.

Finally, each of these paradigms varies in the sensory modalities it draws on in terms of stimulus processing. That is, visual half-field studies inherently rely on the visual modality, and dichotic listening depends on auditory perception. Dual task studies generally use visually presented stimuli (though auditory stimuli have been used in some cases), but DL paradigms also depend on the motor responses of participants in the finger-tapping aspect of the task. Whereas there is a good deal of evidence to suggest that each of these paradigms is suitable for inferring laterality of language function when properly used (see Hull & Vaid, 2002; Segalowitz, 1986; Hellige & Sergent, 1986; Sperry, 1961), there is also ample basis to suspect that the preferential stimulation of different modalities may influence measures of laterality (see Obler, 1981, Hull & Vaid, 2002). For these reasons, each paradigm type was coded and analyzed in the present research.

METHOD

Indentification of Articles in Sample

The research domain for the present meta-analysis included all studies conducted and/or published through the end of December 2002. An exhaustive literature search for published and unpublished studies that assessed cerebral lateralization of language in neurologically healthy bilinguals was conducted through electronic keyword searches of PsycINFO (1872-2002), ERIC (1966-2002), Linguistics and Language Behavior Abstracts (1973-2002), and Dissertation Abstracts International (1861-2002). The keywords used were bilingual* + language, bilingual* + linguistic*, bilingual* + lateral*, bilingual* + hemispher*, and bilingual* + brain, where "*" was an operand that allowed the detection of keywords with various endings (e.g., the keyword "hemispher*" would detect "hemisphere," "hemisphericity," "hemispheric," etc.). The database searches were supplemented by manual searches of the following periodicals dated from January 1998 through December 2002: Brain, Journal of Applied Psycholinguistics, Science, Journal of Memory and Language, Brain and Cognition, Language and Cognitive Processes, Psychological Science, and Journal of Phonetics. In addition, electronic cited-reference forward searches and author name searches were used, as well as a manual review of the reference lists of studies included in the present research. Finally, fugitive sources were pursued through direct correspondence with study authors requesting additional published and unpublished studies that might not have been discovered during our standard searches.

Operationalizations and Sample Selection Criteria

In the neuropsychological literature, the attributes used to define bilingualism and its subtypes have varied widely from study to study. Therefore, to generate clear categories of the bilingual attributes used to select our sample, it was necessary to implement a standard set of parameters. The following operationalizations were thus employed[3]:

- Bilingual – One who possesses some level of communicative ability in at least two languages, regardless of fluency
- Infant bilingual - L2 acquisition onset by the age of six
- Childhood bilingual - L2 acquisition onset after age six and before age 13
- Adolescent bilingual – L2 acquisition onset at or after the age of 13
- Fluent bilingual – One who scored 85% or better on a standardized language proficiency exam (e.g., Test of English as a Foreign Language). Lacking test score data, self-ratings reported in the study were used, as these have been shown to correlate well with standardized proficiency exams. When neither measure was provided, five or more years of formal study was considered to confer fluency.
- Nonfluent bilingual – One who did not meet any of the criteria for fluency.

The criteria for inclusion in the present sample were as follows: published or unpublished studies of brain-intact bilinguals that assessed hemispheric involvement on a linguistic task. In addition, the age of second language acquisition and level of second language fluency must have been stated or inferable in the primary study itself or provided through personal communication with the study authors. The criteria for excluding studies from the sample were inclusion of brain-damaged individuals, failure to measure hemispheric involvement during a linguistic task, or failure to provide adequate quantitative data. In addition, language laterality data users of sign language were excluded. The rationale for this criterion was the abundance of evidence that sign language use is associated with a pattern of brain activity that differs distinctly from that of spoken languages, and especially for deaf sign language users (Neville et al., 1997; Bavelier, Corina, Jezzard, Clark, Karni, Lalwani et al., 1998; see also Segalowitz & Gruber, 1977).

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[3] In a few cases, L2 acquisition age and/or L2 fluency were unstated and unavailable from study authors. We attempted in these cases to infer the values based on other clues in the text (e.g., age of immigration).

Sample of Studies

In all, 71 behavioral language laterality studies with bilinguals were included in the present research synthesis. Of these, 49 were published and 28 were unpublished. Funnel plot analysis revealed no indication of publication bias in the sample (see Figure 1). A total of 97 statistically independent effect sizes were generated for the synthesis of mean effect sizes for first languages (see Appendix A), and 104 for the synthesis of mean effect sizes for second languages (see Appendix B).

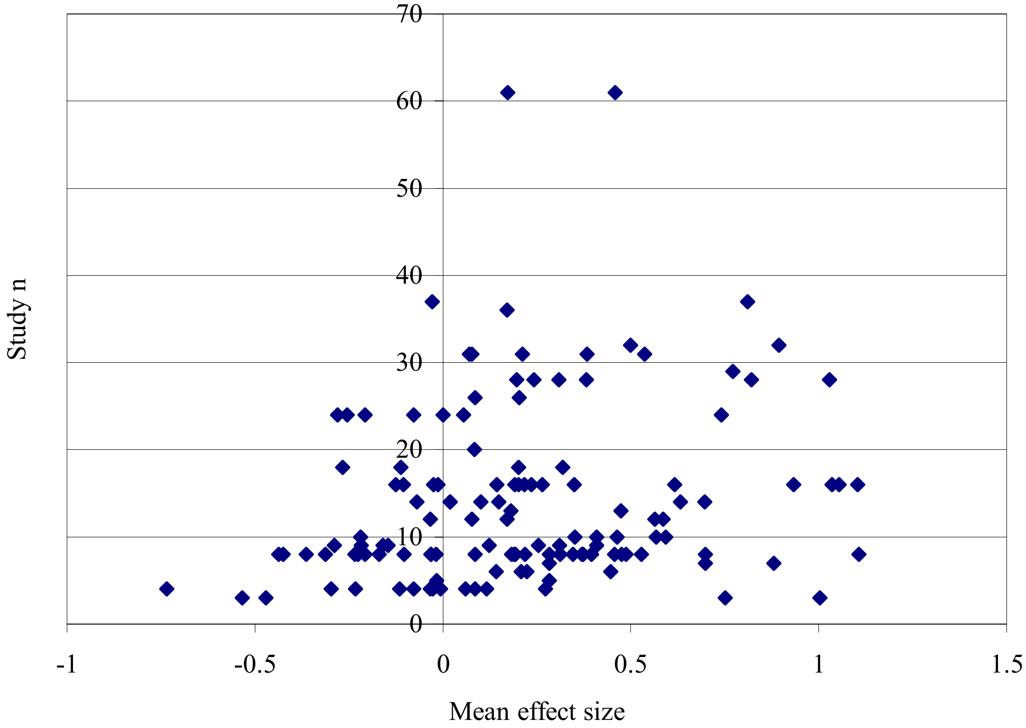

Figure 1. Funnel plot for detecting publication bias.

These studies were analyzed separately, and their effects did not differ from those of the main corpus. Therefore, effect size data from studies with inferred moderator values were included in the present results.

Variables Coded From the Sample of Studies

Two separate analyses were conducted to investigate the factors influencing functional cerebral lateralization in each of a bilingual's two languages. After careful deliberation, I chose to utilize a fixed effects computational model with a categorical model-fitting approach (Hedges & Olkin, 1985) based on our intention to partition the particular and the combined effects of a relatively large number of categorical variables identified in the literature as potential moderators of language laterality. By this rationale, it was assumed that between-study variance not resulting from the operation of moderating variables would be random.[4]

Following Voyer (1996), an hierarchical approach was undertaken in partitioning the aggregated effect sizes in each of the two meta-analytic syntheses. That is, the main effects of L1 and L2 laterality were calculated first, and then these were partitioned into the a priori moderator levels until statistical homogeneity was retained, or until cell sizes became too small to analyze further. However, in certain cases partitioning was continued even after homogeneity was retained (as cell sizes allowed) to address conceptually motivated issues in the literature, such as differences in the direction or magnitude of a given effect.

In the previous section, I operationalized and discussed the conceptual rationale for a number of hypothesized moderators of bilingual laterality. Based on a survey of the studies in our sample, the following data were coded: (1) age of second language acquisition with three independent levels (early, childhood, adolescent[5]), (2) stage of second language acquisition with two independent levels (fluent, nonfluent), (3) participant sex with three independent levels (men, women, combined group),

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[4] An alternative would have been to use a random effects model, which assumes an inherent difference between studies. Given that the sample consisted completely of variations on studies designed specifically to test hemispheric involvement, and the assumption that the bulk of the variance could be explained by moderating variables, the random effects model was rejected as an option.

[5] The "adolescent" category included all bilinguals who had acquired the L2 from age 13 on, and thus adult bilinguals were included in the adolescent moderator level.

(4) experimental paradigm with three independent levels (visual half-field, dichotic listening, dual task), (5) task demand with seven independent levels (word-level vocalized, word-level nonvocalized, phonetic, orthographic, semantic, syntactic, whole-language nonvocalized), (6) context of language use with four independent levels(submerged, integrated, limited, uncertain), (7) language relatedness with three independent levels (related, semi-related, unrelated), (8) English as the second language with two independent levels (English, other), (9) publication status with two independent levels (published, unpublished), and (10) whether age of second language acquisition was directly available or inferred (inferred, available). Interrater agreement was 87%, and inconsistencies were resolved through discussion.[6]

To conduct the overall analyses, an effect size was computed for each moderator in each study. For instance, one effect size was calculated for all men in a given study. A dataset was created to represent each such study-level effect size for men, and these were aggregated into a mean effect size for all men in the sample. To conduct the partitioned analyses, new datasets were created for each moderator level. For instance, one mean effect size represented men who were fluent in the L2, and another represented men who were nonfluent in the L2. Using this method, new datasets were created for each new independent level of the moderating variables. The term "independent levels" was used to refer to the fact that each mean effect size resulting from the categorical modeling represented only one level of each moderator, and the same data could not be used to calculate two different effect sizes at the same level of analysis. To illustrate, within a given study, one data point (i.e., effect size) was computed to represent laterality data drawn from all participants in that study that fell into, for example, level 2 of paradigm (e.g., dichotic listening), <u>and</u> level 2 of participant sex (e.g., women), <u>and</u> level 1 of L2 acquisition age (e.g., infant), <u>and</u> level 1 of L2 acquisition stage (e.g., fluent). As such, this data point would represent the mean laterality score in this study for all fluent, female bilinguals who had acquired the L2 by the age of six and had performed a

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[6] The following moderators did not yield any significant effects in our analyses and thus are not discussed further: English as the second language, context of language use, and publication status.

language task in a dichotic listening paradigm. A completely independent data point would be calculated for all men in our hypothetical example because they would differ from the first group in terms of the participant sex moderator (i.e., the men would represent level 1 of this moderator), even if they were identical on all other moderator levels. Separate effect sizes were calculated in this manner for each possible combination of moderator levels for which data were provided in each study. As a result, depending on the number of moderating variables that could be coded from a given study, the number of independent effect sizes varied.

Calculation of Effect Sizes

Effect sizes were calculated for each study for which sufficient data could be obtained. The majority of studies in the bilingual lateralization literature are characterized by the comparison of two or more groups rather than correlational design. Accordingly, the effect size statistic used to measure the strength of the independent variables in the present research was Cohen's d. Following Hedges and Olkin (1985), effect sizes were calculated by taking the difference between the control and experimental means and dividing by the pooled standard deviation. Specifically, group data associated with left hemisphere performance (e.g., mean tapping rate with the right hand, listening accuracy with the right ear, or reporting accuracy from the right visual hemifield) were treated as the control condition, whereas data associated with the right hemisphere were treated as the experimental condition. That is, effect sizes were computed by subtracting the mean amount of activation in the right hemisphere from that of the left hemisphere, and dividing the difference by the pooled standard deviation. A positive effect size was associated with greater left hemisphere involvement, a negative effect size indicated greater right hemisphere activation, and effect sizes near zero were considered representative of bilateral symmetry.

Once the effect sizes were computed, they were aggregated according to each moderating variable (e.g., L2 acquisition age) and weighted by sample size to provide a summary of the magnitude and direction of each moderator's effects on functional language laterality. Given that the present research assumed a fixed-effects model, the weighting procedure represented a metric of sampling error that involved multiplying the raw effect size by the reciprocal of its variance. The resulting weighted effect size, then, would have more weight in the aggregate analysis if it were more reliably estimated (i.e., if it held relatively less variance). Once the mean sample-weighted effect sizes were computed, the associated 95% confidence intervals were calculated to describe the range within which a given effect size was expected to fall 95% of the time (see Hedges & Olkin, 1985).

The third step of the data analysis was to calculate the homogeneity statistic $\underline{Q}$ for each moderating variable (e.g., L2 acquisition age) to determine whether the $\underline{d}$s for that moderator derived from the same population. The $\underline{Q}$ statistic represents an approximate chi-square distribution with degrees of freedom $\underline{k} - 1$, where $\underline{k}$ is the total number of effect sizes in the set. In cases where the $\underline{Q}$ statistic indicated homogeneity of effect sizes, the set of $\underline{d}$s was considered to have a common population effect, and further partitioning of the set was not necessary.

In cases where homogeneity of effect sizes was not retained within a given moderating variable, categorical models were calculated to investigate whether the variance could be explained by differences between moderator levels (e.g., infant, childhood, or adolescent L2 acquisition age). In a fixed effects model, it is appropriate to make conclusions concerning the levels of the moderating variables that have been coded from the included studies (cf Wood & Quinn, 2003). The categorical models supplied two types of $\underline{Q}$ statistics, one testing homogeneity between levels, $\underline{Q}_b$, and the other type represented the test within each level, $\underline{Q}_w$.

Within a categorical model, a significant $\underline{Q}_b$ statistic indicates that at least some of the aggregate effect sizes for each level of the moderating variable derive from distinct populations. Therefore, when the $\underline{Q}_b$ statistic was significant in a categorical model, direct contrasts that used the chi-square distribute with $\underline{k}$-1 degrees of freedom were conducted on the aggregate effect sizes for each level of the moderating variable. For example, if the $\underline{Q}_b$ statistic indicated heterogeneity of effect sizes for the categorical model describing L2 acquisition age, then direct contrasts were performed between the aggregate ds for the three levels, infant, childhood, and adolescent to determine which of the groups differed from the others. In addition, comparisons of the range of 95% confidence intervals were used to identify groups for which the CIs did not overlap. From these two indicators, three possibilities could arise. First, in cases where the direct contrast between two levels of a moderating variable was significant and the 95% CIs did not overlap, one may have an acceptable degree of confidence that the two groups had different population effect sizes. Second, when the chi-square statistic was significant but there was some amount of overlap in the 95% CIs, it was cautiously suggested that the comparison groups may or may not have derived from differing populations, with more overlap in 95% CIs corresponding with less confidence in a difference between the groups. Finally, in cases where the chi-square statistic was not significant and the 95% CIs overlapped, it was assumed that the comparison groups did not differ. The direct contrasts conducted on L1 vs. L2 comparisons were conducted in the same manner.

In cases where homogeneity could not be retained in a categorical model for a single moderating variable, it was assumed that at least one additional moderating variable was in operation, and further partitioning was performed in an attempt to account for the unexplained variance. That is, categorical models with two moderators (e.g., L2 acquisition age and L2 fluency) were calculated, then three moderators, and so forth, until homogeneity was retained, moderator categories were exhausted, or cell sizes became too small to yield reliable results.

The final step of the data analysis was to compute the amount of observed variance explained by sampling error within each group. Following Hunter and Schmidt (1990), the percent variance due to sampling error was calculated by dividing the expected variance by the observed variance, and multiplying the dividend by 100. Arthur, Bennett, and Huffcutt's (2001) SAS program for calculating expected and observed variance was used to compute the percent variance due to sampling error. The analyses in the present research synthesis were conducted using Johnson's (1993) DSTAT 1.10 software for the meta-analytic review of research literatures.

Identification of Outliers

A data point (i.e., effect size) is considered to be an outlier if its value differs dramatically from other values at the same level (Huffcutt & Arthur, 1995) SAS programs for outlier analysis. Given that meta-analysis is a metric of standard error, the presence of extreme data points can substantially affect the calculated variances and mean effect sizes. Therefore, the identification and removal of outliers is critical to the quality of the meta-analytic results and the appropriateness of their interpretation.

A statistical methodology designed specifically for identifying outliers in meta-analyses, the sample-adjusted meta-analytic deviancy procedure (SAMD), was written in SAS code and published by Huffcutt and Arthur (1995). The present research synthesis used the SAMD procedure to conduct an outlier analysis. The SAMD procedure first compares each effect size, $\underline{d}$ in this case, to the sample-weighted mean effect size (exclusive of the effect size under consideration). Next, the difference is weighted by the total sample size, thus generating the SAMD statistic. The SAMD statistic is calculated for each $\underline{d}$ in the sample, and the values are rank ordered from highest to lowest. The distribution of SAMD statistics approximates a $\underline{t}$ distribution in which effect sizes with extreme SAMD values are identified as potential outliers. Huffcutt and Arthur recommend the use of a scree plot - which plots the rank ordered positions of the SAMD statistics against the actual values of the SAMD statistic - to most accurately determine the cutoff score that should be used to separate outliers from the corpus of SAMD statistics. Deviant data points are easily identifiable because they deviate sharply from the otherwise smooth function described by the SAMD statistics.

Based on the information provided in the scree plot analysis, the SAMD cutoff score of five was determined for effect sizes drawn from L1 data. Two outliers (from Van Lancker & Fromkin, 1973; Kerschner & Jeng, 1972) with SAMD values of 24.25 and 10.37, respectively, were identified within bilingual laterality effect sizes for first languages (see Figure 2). For SAMD values for effect sizes derived within L2 data, the cutoff score was set at four. Six outliers with SAMD values ranging from 4.58 to 7.81 (see Figure 3) were identified (from Kerschner & Jeng, 1972; Rupp, 1980; Soares, 1984; Jin, 1988; Fabbro, et al., 1991; Persinger et al. 2002; Simon, 1984).

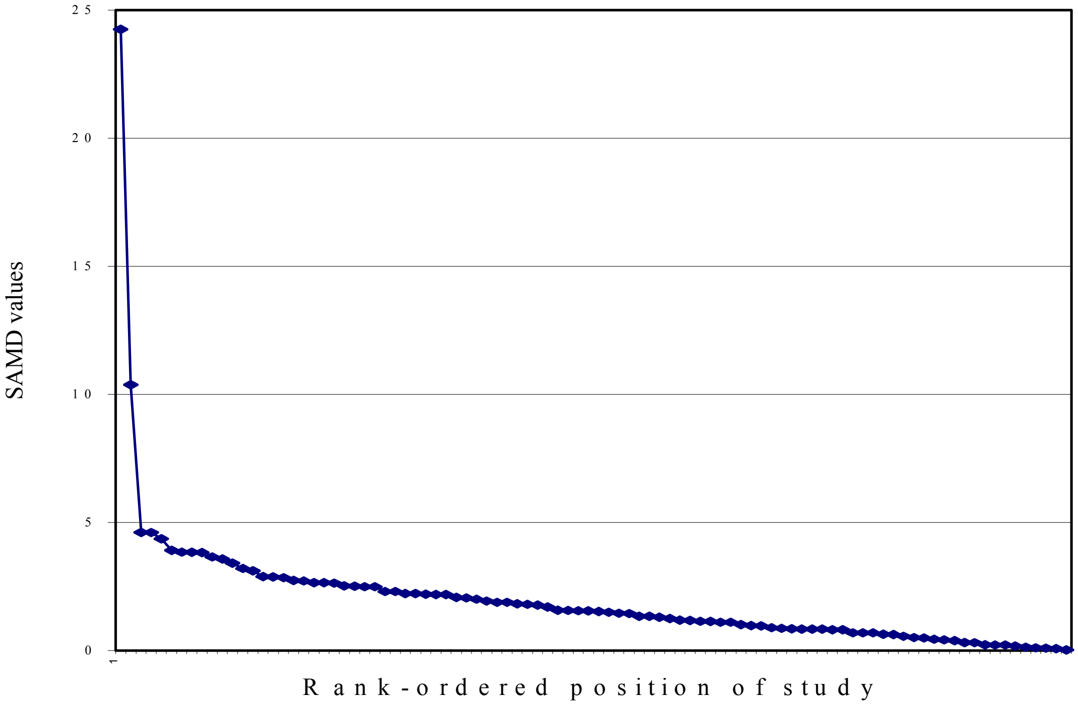

Figure 2. Scree plot for L1 outliers.

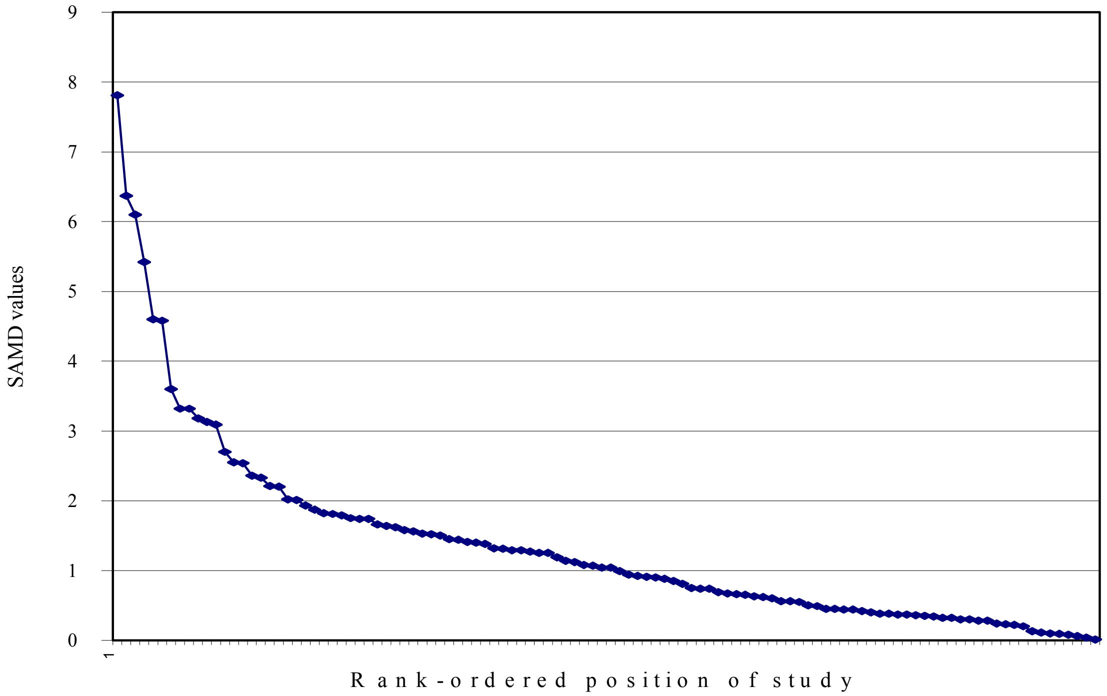

Figure 3. Scree plot for L2 outliers.

The studies were reviewed in an effort to discover whether they differed in some fundamental way from the remaining corpus. It was found that one outlying effect size had been calculated from the aggregated percentage reduction scores from a DT paradigm on five separate verbal tasks, including talking, reciting automatisms, reading aloud, silent reading, and thinking (Soares, 1984). It was determined that the study effect size might have been deviant because it assessed performance across a number of task demands, whereas other studies have generally focused on only one or two. As such, it was determined that outlier status was warranted

Another very large study (n = 280) included 50% left-handers (Simon, 1984). Given a number of claims that left-handers make greater use of the RH in general (as opposed to specific to language processing) along with our observation that almost no left-handers were tested in the main corpus of studies, it was determined that the unusually high number of left-handers in the study gave it a unique character relative to the rest of the sample. That is, it seemed possible that effects of left-handedness swayed the study outcomes. Therefore, outlier status was deemed appropriate.

The remaining potentially deviant data points were derived from studies that used standard single-word tasks in either dichotic listening or visual field paradigms, both of which have been widely used to infer language laterality. Whereas no overtly unique qualities seemed apparent in our review of these few outliers, their strong deviation from the mean d aggregated across the remaining 67 effect sizes suggested that some feature(s) of the outlying studies was inconsistent with the rest of the sample. It was thought that some relatively mundane explanation, such as the presence of undetected errors in data collection, calculation, or reporting, could have been the cause. After careful consideration, the decision to exclude these data points as outliers was based on the unlikelihood that the excessive variance resulted from extreme sampling error, so that the low risk of underestimation from mistakenly excluding extreme non-outliers was outweighed by the risk of overestimating it (see Arthur et al., 2001). For the reasons discussed, each of the outlying data points identified by the SAMD procedure was excluded from further analysis.

RESULTS AND DISCUSSION OF MODERATING EFFECTS ON L1 LATERALITY[7]

Before describing the meta-analytic findings, it is useful to clarify that the primary goal of the present research was to discover the conditions that might underlie the diversity of findings reported in the bilingual laterality literature. As such, a good deal of variance was expected at the most global levels of effect size aggregation (i.e., for first or second languages overall). It is important to note that when variance within a meta-analytic group is reported as significant one should avoid interpreting the associated aggregate effect size, $\underline{d}$, as descriptive of the entire sample, especially in light of the diversity in participant characteristics, methods, and languages that characterizes the bilingual laterality literature. The true value of the present meta-analysis derives from using a number of theoretically identified moderating variables to partition the variance in aggregated $\underline{d}$s into homogeneous categories, and thereby identifying the sources of unexplained variance that address substantive issues in bilingual cognitive research. With this caveat in mind, let us turn now to the meta-analytic results.

The fixed-effects estimate of L1 laterality across the range of subject-, language-, and study-specific characteristics coded in the present research synthesis indicated an overall LH advantage for first languages ($\underline{d} = 0.32$; 95% confidence interval [CI] = 0.25, 0.39; $\underline{k} = 97$). As may be expected, the null hypothesis that the effect sizes were derived from the same population was rejected, as the within-group heterogeneity statistic indicated considerable heterogeneity in the sample, $\underline{Q}_w(96) = 140.20$, $p < .05$. Therefore, fixed-effect categorical modeling of moderating variables was conducted to investigate the circumstances under which language laterality effects might vary. A summary of the L1 effect sizes associated with each of the potential moderating variables, along with the percentage of variance explained by each of the moderator levels, is provided in Table 1.

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[7] The following moderators (with associated between-levels heterogeneity indices) failed to produce any significant results: English as L2, $\underline{Q}_b(1)=0.00$, n.s.; language usage context, $\underline{Q}_b(3)=2.78$, n.s.; publication status, $\underline{Q}_b(1) = 3.12$, n.s.; moderator inferred status, $\underline{Q}_b(1) = 0.27$, n.s.

Table 1

Mean effect size estimates for moderators of L1 laterality

Moderator	k	Total sample size n	Sample-weighted mean d	95% CI	Mean un-weighted d	Homo-geneity statistic Q_w	% Variance explained by sampling error[b]
			L1 dataset partitioned by age of L2 acquisition onset				
Infancy	26	349	0.05	-0.09, 0.19	0.03	10.90	94
Childhood	27	544	0.48	0.36, 0.60	0.35	37.27	88
Adolescence	44	665	0.32	0.21, 0.43	0.28	57.48	85
			L1 dataset partitioned by fluency in L2[c]				
Fluent	86	1230	0.28	0.20, 0.36	0.22	94.53	93
Nonfluent	11	328	0.43	0.28, 0.59	0.31	29.23*	70
			L1 dataset partitioned by experimental paradigm				
Visual	50	496	0.20	0.08, 0.33	0.12	44.32	95
Dichotic Listening	17	410	0.49	0.35, 0.63	0.46	23.49	86
Dual task	30	652	0.28	0.17, 0.39	0.29	49.57	95
			L1 dataset partitioned by linguistic task demands[c]				
Nonvocal – single word	21	424	0.45	0.31, 0.59	0.41	22.82	92
Orthographic – word pairs	43	634	0.22	0.11, 0.33	0.16	47.73	97
Semantic – word pairs	10	162	0.53	0.31, 0.76	0.39	9.26	91
Vocalized – single word	8	156	0.46	0.23, 0.68	0.36	10.62	90
Phonetic – word pairs	8	56	0.26	-0.12, 0.64	0.14	10.82	89

Table 1

Continued

Moderator	k	Total sample size n	Sample-weighted mean d	95% CI	Mean un-weighted d	Homo-geneity statistic Q_w	% Variance explained by sampling error[b]
Syntactic – word pairs	3	72	-0.06	-0.40, 0.26	-0.16	1.64	98
Whole language	4	54	-0.19	-0.56, 0.19	-0.18	0.12	98
			L1 dataset partitioned by participant sex				
Men	20	254	0.16	-0.01, 0.34	0.13	30.03	88
Women	29	408	0.27	0.13, 0.41	0.19	20.98	92
Combined	48	896	0.37	0.28, 0.47	0.30	70.89*	73
			L1 dataset partitioned by relatedness of L1 - L2 linguistic structure[c]				
Related	4	106	0.13	-0.14, 0.40	0.14	0.21	98
Semi-related	67	933	0.27	0.18, 0.36	0.19	74.82	91
Unrelated	26	519	0.42	0.30, 0.55	0.33	46.00*	70

Note. *$p<.05$, df = k-1; k = number of independent effect sizes; CI = confidence interval; L2 = second language. Positive effect sizes (ds) reflect greater activation in the left hemisphere when the CIs do not include zero, and bilateral activation when the CIs include zero. [a] Two outliers with sample-adjusted meta-analytic deviancy (SAMD) scores greater than 5 were removed from the analyses. [b] Following Arthur et al. (2001), samples of studies for which 85% or more variance was explained by sampling error were considered homogeneous with respect to effect sizes. [c] See Appendix C for cells at other levels that had inadequate cell sizes or remaining unexplained variance.

Effects of Individual Difference Variables on L1 Processing

The effect of L2 acquisition age onset revealed that left lateralization of brain functional organization was apparent in childhood bilinguals (d = 0.48; 95% CI = 0.36, 0.60; k = 27), whereas bilinguals in the infant L2 acquisition age subsample were bilaterally activated ($\underline{d} = 0.05$; 95% CI = -0.09, 0.19; $\underline{k} = 26$). The difference in functional language laterality was significant, $\underline{Q}_b(1) = 18.76$, $\underline{p} < .01$. Importantly, the partitioning of L1 variance by the levels of the categorical variable (childhood or infant age of L2 acquisition, in this case) represented in the significant $\underline{Q}_b$ value was considered to satisfactorily explain the heterogeneity in the overall effect size distribution (Lipsey & Wilson, 2001).

The meta-analysis also found limited evidence that the subsample of childhood bilinguals may have been more LH dominant relative to bilinguals who had acquired the L2 during adolescence or later ($\underline{d} = 0.32$; 95% CI = -0.21, 0.43; $\underline{k} = 44$), as indexed by significant heterogeneity between the two groups, $\underline{Q}_b(1) = 18.76$, $\underline{p} < .01$. The result is reported as limited because the CI for the aggregated language laterality effect size in adolescent bilinguals was completely overlapped by the CI of the childhood mean effect size. In such cases, confidence that the groups of interest showed a true difference is compromised (Borenstein & Rothstein, 1999). It remains relevant, however, that <u>all effect size variance within bilinguals who performed language tasks on the L1 was explained when the variance was partitioned by the three levels of L2 acquisition age,</u> indicating that the L2 acquisition age moderator was a reliable predictor of bilingual laterality.

Although categorical modeling by L2 acquisition age was sufficient to explain laterality differences in bilinguals, additional categorical models were tested in the interest of investigating the influences of other theoretically identified sources of difference between studies in this literature. Model-fitting by level of <u>L2 fluency</u> showed that the set of fluent bilinguals was LH dominant for language processing ($\underline{d} = 0.48$; 95% CI = 0.36, 0.60; $\underline{k} = 27$), with homogeneity retained within the level, $\underline{Q}_w(85) = 94.53$, n.s. However, the predictive value of L2 fluency as a moderating variable was limited in two ways. First, homogeneity was rejected within the nonfluent level, $\underline{Q}_w(10) = 24.21$, $\underline{p} < .02$, indicating the presence of unexplained variance in effect sizes. Second, the between-groups heterogeneity index failed to attain significance, $\underline{Q}_b(1) = 1.55$, n.s, indicating that the fluent and nonfluent bilingual subsamples were not differentially lateralized overall. The pattern of meta-analytic results suggests that the residual variance may have been associated with some other moderator, especially for nonfluent bilinguals. Unfortunately, the sample of bilinguals with nonfluent skill in the L2 was too small to allow further partitioning of the unexplained variance within that group.

The third participant-specific characteristic that was modeled was sex composition of the sample. Almost twice as many effect sizes in our sample were drawn from studies that did not distinguish between the scores of men and women, i.e., the data were collapsed into a mixed sex group. The sample-weighted mean $\underline{d}$ for the mixed sex level of effect size aggregation represented significantly more left lateralization than that found for men, $\underline{Q}_b(1) = 4.21$, $\underline{p} < .05$, but not women, $\underline{Q}_b(1) = 1.50$, n.s. Indeed, the between-levels heterogeneity statistics showed that women did not differ significantly from men or from the mixed sex group. However, inspection of the aggregated mean effect sizes suggested that bilingual women ($\underline{d} = 0.27$; 95% CI = 0.13, 0.41; $\underline{k} = 29$) tended toward greater LH lateralization than bilingual men, who were bilaterally activated, ($\underline{d} = 0.16$; 95% CI = -0.01, 0.34; $\underline{k} = 20$). It is possible that the trend toward differential functional laterality in bilingual men and women may have been magnified in the larger subsample at the mixed sex level of aggregation. That is, given that homogeneity was retained within the separate subsamples of bilingual men and women, but not within the mixed sex level, one possibility that might address the heterogeneity within the mixed sex level is that the level could have been comprised of a relatively greater number of women, in which case the trend toward sex-related differences in functional language laterality may have been responsible for the unexplained variance within the larger mixed sex level. However, not enough information on the ratios of men and women was available in the mixed sex studies to evaluate this idea further.

Fortunately, the large size of the mixed sex level, and the only level for which homogeneity was rejected, permitted further partitioning of the unexplained variance within the mixed sex subsample. The fitting of the mixed sex group to categorical models was attempted with the other moderating variables that were coded in the present meta-analysis. Of these, only L2 acquisition age was successful in reducing the unexplained variance in the mixed sex group (see Appendix C for a summary of the results of unsuccessful modeling attempts).

The partitioning of variance within the mixed sex subsample by the levels of L2 acquisition age yielded homogeneity for the bilaterally activated infant-mixed sex group, ($\underline{d}$ = 0.05; 95% CI = -0.16, 0.27; $\underline{k}$ = 12), $\underline{Q}_w(11)$ = 6.09, n.s., and for the LH dominant adolescent-mixed sex group ($\underline{d}$ = 0.41; 95% CI = 0.25, 0.57; $\underline{k}$ = 19). The two did not differ, $\underline{Q}_w(18)$ = 22.64, n.s. The LH dominant childhood-mixed sex group failed to retain homogeneity of effect sizes in this model ($\underline{d}$ = 0.48; 95% CI = 0.34, 0.63; $\underline{k}$ = 17), and further attempts to partition the remaining variance in the childhood-mixed sex subsample were also unsuccessful (see Appendix C).

A plausible explanation regarding the unexplained variance in the childhood-mixed sex group concerns the possible influence of varying contexts of language exposure that might be expected for children acquiring two languages. These include (but are not limited to) formal vs. informal manner of L2 acquisition (Galloway & Krashen, 1980). It may be that some combination of context and amount of L2 use, manner of L2 acquisition, or other societal influences might interact to differentially organize functional cerebral lateralization in children who are acquiring a second language. Unfortunately, these have been understudied areas in bilingual laterality research, and adequate information regarding specific contexts of language exposure was not available in the sample of studies. It is hoped that future bilingual laterality research will pursue this possibility.

Effects of Language-Specific Moderating Variables on L2 Processing

Language-specific moderators of the functional cerebral lateralization of language were also tested in the present meta-analysis, but were found to be of limited usefulness in explaining the variance in first language effect sizes. Attempts to partition L1 variance according to the levels of relatedness between the linguistic structures of first and second languages showed restricted, yet revealing, effects. Specifically, the vast majority of bilingual laterality research has involved semi-related languages, i.e., those occupying separate branches of a shared root language. In particular, combinations of English and various European languages were paired most frequently in the primary studies. The sample-weighted mean effect size of first languages that were semi-related to the L2 in terms of linguistic structure showed a statistically reliable LH effect for the first language ($\underline{d} = 0.27$; 95% CI = 0.18, 0.36; $\underline{k} = 67$), $\underline{Q}_w(66) = 74.82$, n.s.

Linguistic relatedness as a moderating variable of first language functional lateralization, at least as operationalized in the present research, was inadequate for two reasons. First, the number of comparisons involving first languages that were either structurally related or structurally unrelated to the L2 was too small to be reliably estimated (see Appendix). The second limitation involved the observation that 70% of the bilinguals whose data were represented in the semi-related subsample of first languages had learned the L2 during childhood or adolescence. It has already been shown that late bilinguals were significantly more left lateralized than infant bilinguals. Moreover, there were comparable numbers of bilinguals with semi-related languages in the child and infant L2 acquisition age levels reported above (63% and 62%, respectively). Therefore, if the mean LH effect that was found for first languages with a semi-related L2 were in fact a unique result of linguistic relatedness, one might have expected the LH effect of semi-related linguistic structure to have had a prevailing influence on the mean effect size of the infant bilingual subsample. It is suggested that a more likely interpretation is that the LH effect found for first languages from a semi-related pair of languages was a result of the disproportionate percentage of LH dominant late bilinguals in that subsample.

Another language-based moderator of bilingual laterality, this one involving potentially distinct processing effects for the task demands associated with different components of language, uncovered a disparity in the levels of language that have been investigated. Out of the 97 independent $\underline{d}$s that were computed for first languages, over 40% have examined the effects of processing for orthographic characteristics of word pairs. Orthographic processing was the least LH lateralized level of language components with statistically reliable aggregated effect size estimates. This finding is not surprising in light of the purported nature of tasks that involve the processing of surface level language components, such as orthography, which are thought to increase RH involvement relative to, for example, the processing of words for meaning. In fact, the mean LH dominance for orthographic judgments about word pairs was significantly lower ($d = 0.22$; 95% CI = 0.11, 0.33; $k = 43$) than that for semantic processing of word pairs ($d = 0.53$; 95% CI = 0.31, 0.76; $k = 10$), as indicated by the significant between-groups heterogeneity statistic, $Q_b(1) = 5.97$, $p < .05$. The finding of differential lateralization between the two levels was further validated by the presence of homogeneity within the language-component subsamples representing semantic $Q_w(9) = 9.26$, n.s., and orthographic processing, $Q_w(42) = 47.73$, n.s.

The third language component for which it was possible to calculate a statistically reliable mean effect size involved word level language processing. Language tasks such as lexical decision, that required nonvocalized responses to single-word stimuli, showed a moderate LH mean effect ($d = 0.45$; 95% CI = 0.31, 0.59; $k = 10$), and homogeneity was retained in the subsample, $Q_w(20) = 22.82$, n.s. It is worth noting that the sample-weighted mean effect size associated with nonvocalized single word processing was quite similar to the mean d for semantic judgments about word pairs, $Q_b(1) = 0.38$, n.s., but was significantly different from the aggregated effect size for orthographic processing, $Q_b(1) = 6.39$, $p < .05$.

One useful aspect of the categorical modeling of language components is the robust difference obtained in mean effects between tasks thought to involve “deep” processing (e.g., semantic processing) and those thought to involve “surface” processing (e.g., orthographic processing). This finding provides support for the notion of differential hemispheric involvement as a function of the level or complexity of processing involved in linguistic tasks. In view of this finding, future laterality studies should be carefully designed to include or else control for task related processing demands as a variable.

Effects of Methodology-Specific Moderating Variables on L1 Processing

With respect to outcomes related to the partitioning of L1 variance by experimental paradigm, the meta-analysis showed that mean effect sizes of bilingual language lateralization varied by paradigm, $Q_b(2) = 9.22$, $p < .01$. Examination of aggregated ds within the visual paradigm revealed a small but reliable LH effect ($d = 0.20$; 95% CI = 0.08, 0.33; $k = 50$), $Q_w(49) = 44.32$, n.s. The mean weighted d for the dual task paradigm also reflected homogeneity, $Q_w(29) = 49.57$, n.s., with a modest LH effect ($d = 0.28$; 95% CI = 0.17, 0.39; $k = 30$). Mean effects of dual task and visual paradigms did not differ from each other, $Q_b(1) = 0.84$, n.s., but each was significantly less LH lateralized than the mean effect size from the dichotic listening paradigm, $Q_b(1) = 5.16$, $p < .05$, and $Q_b(1) = 8.78$ $p < .01$, respectively.

The finding that the dichotic listening paradigm had a stronger LH effect on L1 processing relative to dual task and visual paradigms is important as an instance of caution against considering all methods of language lateralization study as yielding equivalent laterality outcomes. However, the effectiveness of the paradigm moderator at explaining L1 effect size variance is conceptually less compelling than the participant-based explanation provided by the categorical modeling of L2 acquisition age. That is, the bilingual laterality literature has a rich history of theoretical and experimental research into the cognitive outcomes of bilingualism and its subtypes. The literature has been mainly concerned with studying neural correlates associated with variations across bilinguals than studying variations arising from differences in methodologies for testing individual differences. Therefore, the findings from our meta-analysis that identified L2 acquisition age as the primary moderator of substantive and statistical relevance to the prediction of cerebral functional asymmetries in first languages is of relatively greater importance to the advancement of theoretical and experimental approaches in bilingual laterality research.

RESULTS AND DISCUSSION OF MODERATING EFFECTS ON L2 LATERALITY

As with the analysis for the first language, the primary motivation for the analysis of mean effects of functional cerebral lateralization for bilinguals' second language was to identify reliable sources of effect size variance that have been hypothesized and studied. Therefore, it was somewhat surprising to find that the quantitative synthesis of 104 independent effect size estimates computed from our broad survey of the experimental bilingual laterality literature revealed homogeneity in the main effect, $\underline{Q}_w(103) = 80.63$, n.s. In other words, the variety of theoretically identified moderating variables of second language that were coded in the present research showed similar mean effects across bilingual subtypes, language-specific differences, and methodologies. Specifically, the aggregated mean effect size indicated a small LH effect across moderating variables ($\underline{d} = 0.25$; 95% CI = 0.17, 0.32; $\underline{k} = 104$).

It is important to emphasize that bilinguals with infant, childhood, and adolescent L2 acquisition ages were disproportionately represented in both the sample of studies and the mean aggregated effect size for L2, with infant bilinguals comprising less than 30% of the total sample (27% was the case in the L1 dataset). Some of the levels of other moderating variables were similarly disproportionately represented. Therefore, an examination of the relative direction and strength of effects as they related to different bilingual contexts was conceptually (if not statistically) warranted. Below is described the results of the categorical modeling of theoretically guided moderator categories for second languages. Notably, homogeneity was retained at every moderator level (as would be expected given the lack of unexplained variance in the main effect), and, as such, all can be considered statistically reliable (see Table 2 for a detailed summary of L2 effect size estimates and heterogeneity statistics by moderator level).

Another important observation concerning the L2 analysis of mean effect sizes is that the pattern of results across mean L2 effect sizes almost perfectly mirrored that found in the analysis of mean laterality effects for first languages. Taken together with the lack of heterogeneity in the L2 sample, our presentation and results of the L2 analysis will be largely descriptive in nature.

Table 2

Mean effect size estimates for moderators of L2 laterality

Moderator	k	Total sample size n	Sample-weighted mean d	95% CI	Mean un-weighted d	Homo-geneity statistic Q_w	% Variance explained by sampling error[b]
L2 dataset partitioned by age of L2 acquisition onset							
Infancy	31	339	0.12	-0.03, 0.27	0.10	17.64	90
Childhood	23	399	0.32	0.18, 0.36	0.28	19.56	95
Adolescence	50	776	0.25	0.15, 0.36	0.23	40.64	96
L2 dataset partitioned by fluency in L2							
Fluent	87	1169	0.22	0.14, 0.30	0.18	57.37	79
Nonfluent[c]	17	345	0.34	0.19, 0.49	0.35	21.24	89
L2 dataset partitioned by participant sex							
Men	20	216	0.08	-0.11, 0.27	0.08	8.12	98
Women	28	271	0.18	0.01, 0.35	0.17	13.86	93
Mixed	56	1027	0.30	0.21, 0.38	0.27	54.06	98
L2 dataset partitioned by experimental paradigm							
Visual	59	660	0.14	0.03, 0.25	0.11	39.66	90
Dichotic listening	20	407	0.41	0.27, 0.55	0.36	14.76	95
Dual task	25	447	0.26	0.13, 0.39	0.31	17.44	94

Table 2

Continued

Moderator	k	Total sample size n	Sample-weighted mean d	95% CI	Mean un-weighted d	Homo-geneity statistic Q_w	% Variance explained by sampling error[b]
			L2 dataset partitioned by linguistic task demands				
Vocal response – word level	15	336	0.21	0.05, 0.36	0.24	16.52	98
Nonvocal – single word	19	326	0.44	0.28, 0.59	0.51	11.27	98
Phonetic – word pairs	8	48	0.13	-0.27, 0.54	0.12	2.84	89
Orthographic – word pairs	47	580	0.20	0.08, 0.31	0.14	26.78	91
Semantic – word pairs	11	174	0.27	0.06, 0.48	0.10	12.14	94
Syntactic – word pairs	2	32	-0.11	-0.60, 0.38	-0.11	0.02	98
Whole language comprehension	2	18	-0.22	-0.88, 0.43	-0.22	0.04	98
			L2 dataset partitioned by L1 – L2 linguistic structure				
Related	5	67	0.18	-0.16, 0.52	0.18	0.89	98
Semi-related	71	850	0.22	0.13, 0.32	0.19	48.23	95
Unrelated	28	597	0.29	0.17, 0.40	0.26	30.51	92

Note. *p<.05, $df = k$-1; k = number of independent effect sizes; CI = confidence interval. Positive effect sizes (ds) reflect greater activation in the left hemisphere when the CIs do not include zero, and bilateral activation when the CIs include zero. [a] Six outliers with sample-adjusted meta-analytic deviancy (SAMD) scores greater than 4 were removed from the analyses. [b] Following Arthur et al. (2001), samples of studies for which 85% or more variance was explained by sampling error were considered homogeneous with respect to effect sizes. [c] See Appendix C for cells at other levels that had inadequate cell sizes or remaining unexplained variance.

Effects of Individual Difference Variables on L2 Processing

The L2 analysis of bilingual laterality effect sizes indicated that adolescent and childhood bilinguals were significantly LH dominant for second languages (d = 0.25; 95% CI = 0.15, 0.36; k = 23), and (d = 0.32; 95% CI = 0.18, 0.36; k = 23, respectively). As in the L1 analysis, the mean effect sizes for the childhood and adolescent levels did not differ from each other. The LH effect for the childhood L2 acquisition group was stronger than that of the adolescent group. Also as in the L1 analysis, the mean effect size confidence interval (CI) of the adolescent group was completely overlapped by that of the childhood group.

Whereas the mean effect size for second language laterality in the infant L2 acquisition group showed bilateral hemispheric involvement (d = 0.12; 95% CI = -0.03, 0.27; k = 31) as it had for L1, the L2 analysis showed that the infant group was only marginally less LH lateralized relative to the childhood group, $Q_b(1) = 3.68$, p < .06, n.s., and not significantly different in lateralization than the adolescent group, $Q_b(1) = 2.38$, p < .12, n.s. Consideration of the mean effect sizes for the levels of L2 acquisition age for first vs. second languages provides some insight into why the effect sizes of early vs. late acquisition groups did not reach a significant difference in the L2 analysis. That is, the infant L2 acquisition group was slightly less LH lateralized for L1 relative to L2, and each of the late L2 acquisition age groups showed the reverse pattern (i.e., they were slightly more LH lateralized for L1 relative to L2). Although these within group differences in L1 vs. L2 lateralization patterns were not significantly different, it is entirely possible that the slight but opposing shifts in laterality between early and late bilinguals may have negated the significant difference.

Categorical modeling of L2 fluency also produced a pattern of results similar to the one reported in the L1 analysis. One major difference, however, was that the nonfluent bilingual subsample was large enough in the L2 analysis to be considered statistically reliable, whereas it had not been for the L1 analysis. The categorical model of L2 mean effect sizes by skill level in the L2 showed that nonfluent bilinguals demonstrated a stronger, though still modest, LH mean effect for L2 processing (d = 0.34; 95% CI = 0.19, 0.49; k = 17) relative to that in fluent bilinguals (d = 0.22; 95% CI = 0.14, 0.30; k = 87). Two observations concerning the fluent and nonfluent L2 subsamples may be relevant in interpreting the nonsignificant magnitude difference in mean effect sizes. First, the nonfluent sample, while statistically reliable, was less than 20% of the total bilingual sample. Moreover, only two data points were based on bilinguals with infant L2 acquisition. In other words, almost 90% of the nonfluent subsample in the analysis included data points drawn from bilinguals with childhood or adolescent L2 acquisition ages. Given that the later L2 acquisition was associated with a relatively stronger LH mean effect, and that this effect was operating in all but 10% of the nonfluent subsample, one may question whether the present finding of LH dominance in the L2 mean aggregated d for nonfluent bilinguals would hold up if equivalent numbers of bilinguals with infant L2 acquisition age and nonfluent L2 skill had been represented.

Comparisons of the L2 mean aggregated ds at the three levels of participant sex once again showed the identical pattern as that revealed in the L1 analysis. In particular, the mixed sex condition displayed the strongest LH mean effect (d = 0.30; 95% CI = 0.21, 0.38; k = 56), the mean aggregated d in the women only sample showed a more modest LH effect (d = 0.18; 95% CI = 0.01, 0.35; k = 28), and that in the men only sample exhibited bilateral symmetry (d = 0.08; 95% CI = -0.11, 0.27; k = 20).

It is worth noting that the CI for the women only sample on the L2 was very close to including zero, in which case the result would have indicated bilateral hemispheric involvement for L2 processing. Another interesting observation in the present sample was that, in the women only level, early and late L2 acquisition groups were almost equally represented (45% and 55%, respectively). This may, at least in part, underlie the finding of less hemispheric asymmetry for L2 processing relative to the L1 women-only sample, in which late L2 acquirers were over represented. Whereas the L2 women-only sample was of a reliable size (k = 27, n = 271), it remains to be seen whether additional data points drawn from bilingual women with more varying acquisition histories will still support the present finding of a slight LH dominance for L2 processing in bilingual women.

Finally, an idiosyncratic feature was observed in the sample of bilingual women tested in the L2 that could have led to potentially misleading results where sex-related differences were concerned. Specifically, examination of the sample of women in the L2 meta-analytic dataset revealed that all were fluent in the L2. Given that L2 fluency was shown to be associated with LH effects for language processing, it is unclear whether LH dominance would have remained the pattern for bilingual women overall had there been a more equal representation of skill levels in the L2. Finally, although the cell sizes were too small to infer a statistically reliable result, it was interesting to note that women trended toward bilateral activation during dichotic listening tasks, and more so than men, as had been found in the previous meta-analysis by Hull and Vaid (2002).

Effects of Language-Specific Moderating Variables on L2 Processing

The L2 pattern of results that emerged from the categorical model fitting by levels of language component showed two interesting differences from the L1 results. First, the L2 analysis contained sufficient data points to allow the analysis of the language component level representing vocalized responses to single word stimuli, for which a small LH effect was detected (d = 0.21; 95% CI = 0.05, 0.36; k = 15). Interestingly, the vocalized level showed a smaller LH effect than the nonvocalized level of single word processing in L2 (d = 0.44; 95% CI = 0.28, 0.59; k = 19).

This finding, though not significant, was unexpected in light of the rather large literature indicating that the LH is preferentially involved in speech processing. Inspection of the subsample compositions showed that nearly half (46%) of the nonvocalized-word subsample included infant bilinguals (who have been shown in both analyses to be bilaterally symmetrical), whereas the vocalized-word sample was comprised mostly of late acquisition bilinguals (74%), who have consistently been shown in both analyses to be LH dominant for language processing. Therefore, although the difference between the mean effect sizes for vocalized vs. nonvocalized processing of single words in the L2 was non-significant in the present analysis, one might expect to find more equivalence in effects, or even a pattern reversal, had early and late bilinguals in the L2 acquisition age group been more equally represented.

The second (but again, nonsignificant) difference in the pattern of results for the L1 and L2 analyses on language component involved the results for semantic processing. Specifically, semantic processing of word pairs in L1 had shown the largest LH effect ($\underline{d}$ = 0.53; 95% CI = 0.31, 0.76; $\underline{k}$ = 10). The L2 analysis showed a relatively smaller LH effect for semantic word-pair processing ($\underline{d}$ = 0.27; 95% CI = 0.06, 0.48; $\underline{k}$ = 11) than for nonvocalized single-word processing ($\underline{d}$ = 0.44; 95% CI = 0.28, 0.59; $\underline{k}$ = 19), where the latter showed the largest LH effect in the L2 analysis. As noted, these differences were nonsignificant, but it remains to be seen whether the inclusion of additional data points from future studies may bring these trends to significance.

In the L2 analysis, the magnitude of the L2 semantic word-pair processing effect was more comparable to (but slightly more LH lateralized than) that of the L2 orthographic word-pair processing effect ($\underline{d}$ = 0.20; 95% CI = 0.08, 0.31; $\underline{k}$ = 47). This qualitative difference in the pattern of results between the two analyses is particularly striking because of the almost perfect overlap of mean effect size magnitude between L1 and L2 analyses for the processing of word pairs for orthography and nonvocalized processing of single words. Put another way, the only language component, indeed the only level of any moderator, that deviated from the consistent pattern of findings between the L1 and L2 analyses (albeit a nonsignificant deviation) was the semantic processing of word pairs, which tended toward less left lateralization in the L2 analysis.

Once again, inspection of the composition of L2 acquisition age groups in the language component subsamples provides a possible explanation for the pattern of results. The L2 mean lateralization effect for semantic processing was drawn from a sample that included nearly equal proportions of infant L2 acquisition (55%) and later L2 acquisition (45%) bilinguals. The sample underlying the mean effect size for semantic processing of word pairs in L1, on the other hand, was largely composed of later L2 acquisition bilinguals (70%). As has been shown in several instances so far, different proportions of early and late bilinguals within a particular subsample may be related to effect size patterns that are consistent with the mean effect of the group that was more heavily represented in the subsample.

Partitioning L2 effects by levels of linguistic relatedness of the two languages of bilinguals yielded a comparably sized LH effect for semi-related languages ($\underline{d} = 0.22$; 95% CI = 0.13, 0.32; $\underline{k} = 71$) as was found in the L1 analysis. However, the L2 analysis revealed one additional finding of interest. There were a sufficient number of L2 data points for unrelated language pairs to provide a statistically reliable mean effect size, unlike the situation in the L1 analysis. Interestingly, the L2 mean effect for structurally unrelated language pairs was somewhat more LH lateralized ($\underline{d} = 0.29$; 95% CI = 0.17, 0.40; $\underline{k} = 28$) than that for semi-related languages. Given that the majority of unrelated language pairs included differences in orthography (e.g., Hebrew vs. English, Chinese vs. English), one might have expected to find, if anything, <u>less</u> LH lateralization for unrelated pairs, as orthographic processing could arguably be a more well developed aspect of the language processing skills. It was not surprising, therefore, to discover that the sample of bilinguals underlying the mean effect size for L2 processing for the level of unrelated language pairs included 75% late bilinguals and 25% infant bilinguals. Thus, the greater LH effect of unrelated than for related language pairs could conceivably be attributed to acquisition age composition of the former subsample.

Effects of Methodology-Specific Moderating Variables on L2 Processing

Partitioning by experimental paradigm showed the, by now, expected pattern (i.e., similar to the L1 analysis) of a moderate LH effect for L2 processing in the dichotic listening paradigm (d = 0.41; 95% CI = 0.27, 0.38; k = 20), a relatively smaller LH effect for the dual task level (d = 0.26; 95% CI = 0.13, 0.39; k = 25), and the smallest LH effect for L2 processing the visual paradigm (d = 0.14; 95% CI = 0.03, 0.25; k = 59). There were no unexpected findings when L2 effects were partitioned by paradigm.

Summary of L1 and L2 Analyses and Caveats

The two analyses of the patterns of language laterality effects in bilinguals tested a number of moderating variables that had strikingly similar influences on first and second languages. Whereas effect sizes at the individual levels of categorical models were not identical between the two analyses, the similarities provide a persuasive argument for an absence of significant differences between the functional lateralization of a bilingual's two languages, regardless of the individual's acquisition age, skill level, or sex, and likewise insensitive to differences between how the two languages that were learned, between the language component being processed, or between experimental paradigms.

To address inconsistent ideas in the bilingual laterality literature concerning whether L1 and L2 are different language entities, or at least are functionally organized as such, direct contrasts were carried out on the mean effect sizes computed for each level of every moderating variable coded in the present research. The goodness-of-fit statistics clearly showed an absence of significant differences in mean effects sizes between L1 and L2 in every moderator category (see Table 3). The finding suggested that, within individuals, the bilingual brain processed language similarly, regardless of language acquisition order.

Notably, the present results replicated those of the two earlier meta-analyses (Hall & Vaid, 1990; Hull & Vaid, 2002) in two ways. First, in terms of similarity in first and second language laterality, homogeneity had been retained for the mean bilateral effect found for language processing within the early bilingual group in the Hull and Vaid analysis, in which both languages had been considered first languages. Second, both earlier meta-analyses had found that late bilinguals were significantly more LH lateralized than early bilinguals, the same pattern as detected in the present results. The consistency of results between the three meta-analyses provides additional confidence that language organization is qualitatively different for early bilinguals relative to late bilinguals. Moreover, the consistency of results supports the idea that, within L2 acquisition age subgroups, the bilingual brain treats languages similarly, as no evidence was found for a distinction between first and second language cerebral representation.

Table 3

Summary of mean effect size comparisons for first vs. second languages

Moderator level for L1 vs. L2 comparison	Number of Comparisons C	Fit Statistic X^2	Interpretation of L1 vs. L2 comparisons
L2 acquisition onset in infancy	26	0.37, n.s.	No difference for infant bilinguals
L2 acquisition onset in childhood	23	0.94, n.s.	No difference for child bilingual
L2 acquisition onset in adolescence	42	0.00, n.s.	No difference for adolescent bilinguals
Fluency in L2	88	0.00, n.s.	No difference for fluent bilinguals
Nonfluency in L2	5	2.24, n.s.	Small cell size yields unreliable mean effect sizes
Men	19	0.16, n.s.	No difference in men
Women	28	0.59, n.s.	No difference in women
Mixed sex groups	46	0.00, n.s.	No difference in mixed sex groups
Visual paradigm	49	0.01, n.s.	No difference in visual paradigms
Dichotic listening paradigm	16	0.00, n.s.	No difference in dichotic listening
Dual task paradigm	26	0.01, n.s.	No difference in dual task paradigms

Table 3

Continued

Moderator level for L1 vs. L2 comparison	Number of Comparisons C	Fit Statistic X^2	Interpretation of L1 vs. L2 comparisons
Vocal response, single word stimuli	8	3.19, n.s.	Small cell size yields unreliable mean effect sizes
Nonvocal response, single word stimuli	19	0.49, n.s.	No difference for nonvocalized words
Phonetic word judgments	8	0.21, n.s.	Small cell size yields unreliable mean effect sizes
Orthographic word judgments	41	0.45, n.s.	No difference for word pair judgments
Semantic judgments, word pairs	10	2.81, n.s.	No difference for word pair judgments
Syntactic judgments, word pairs	2	0.02, n.s.	Small cell size yields unreliable mean effect sizes
Whole language comprehension	2	0.00, n.s.	Small cell size yields unreliable mean effect sizes
Relatedness of linguistic structure	4	0.01, n.s.	Small cell size yields unreliable mean effect sizes
Semi-related linguistic structure	66	0.01, n.s.	No difference in semi-related languages
Unrelated linguistic structure	24	0.28, n.s.	Small cell size yields unreliable mean effect sizes

Note. df = C-1; C = number of comparison categories.

While the present meta-analysis of the behavioral bilingual laterality literature identified age of L2 acquisition as the best predictor of functional language organization in the brain, it did not rule out an influence of L2 skill. The present research did not find evidence of skill related differences in mean language lateralization effect sizes, but it may have been that the categories were not sensitive enough to detect lateralization differences between fluent and nonfluent bilinguals. Certainly it was the case that the paucity of data points for nonfluent bilinguals disallowed a number of comparisons, and may have weakened the strength of trends that were found. Until far greater numbers of nonfluent bilinguals are tested in behavioral language laterality research, questions concerning the presence and strength of differential effects of L2 fluency on bilingual laterality cannot be fully answered by this literature.

The magnitude of the effects of L2 acquisition age, however, was assessed in the present research. It was revealed that partitioning the mean effects in fluency levels by the levels of L2 acquisition age mattered for patterns of hemispheric involvement during language processing. In particular, the mean effect size for fluent bilinguals overall was LH dominant, but when the fluent sample was partitioned by L2 acquisition age, the overall LH mean effect for fluent bilinguals ($\underline{d} = 0.25$; 95% CI = 0.17, 0.32; $\underline{k} = 104$) disappeared for bilinguals who had acquired the L2 by the age of six ($\underline{d} = 0.12$; 95% CI = -0.13, 0.27; $\underline{k} = 31$). Moreover, within bilinguals who acquired the L2 later in life (either in childhood or adolescence), partitioning the mean effect sizes by fluency level did not matter, i.e., late bilinguals were LH dominant for language either whether they were fluent in the L2 ($\underline{d} = 0.25$; 95% CI = 0.17, 0.32; $\underline{k} = 104$) or not ($\underline{d} = 0.32$; 95% CI = 0.17, 0.48; $\underline{k} = 15$).

One situation I could not test was whether partitioning early L2 acquisition age by L2 fluency levels would alter the direction of effects for bilinguals who acquired the L2 early but were nonfluent, because behavioral data for such bilinguals have simply not appeared in the behavioral bilingual laterality literature. Even so, the opposing patterns of directional change found in the partitions that were possible suggest that age of L2 acquisition was the superior predictor.

Aside from the small number of data points associated with language processing in nonfluent bilinguals, several other data limitations in the sample of bilingual laterality studies prevented complete tests of each level of the moderating variables that were addressed. Underrepresented levels included structurally related L1-L2 pairs (four data points in L1 and five in L2), whole language processing (two data points in L1 and two in L2), syntactic processing (two data points in L1 and two in L2), phonetic processing (eight data points in L1 and eight in L2), vocalized responses to single-word stimuli (eight data points in L1 and 25 in L2). Other moderator levels contained scarcely enough data points to be considered statistically reliable, making the threat of misleading mean effect sizes based on disproportionate numbers of bilingual subtypes (i.e., bilaterally activated early vs. LH dominant late second language acquirers) a distinct possibility. A more complete understanding of the effects of the various moderators will require that future bilingual laterality studies be designed to include them.

GENERAL DISCUSSION AND CONCLUSIONS

Two conclusions of the present research synthesis are 1) that functional cerebral lateralization is similar for first and second languages of bilinguals, and 2) that age of L2 acquisition significantly influences the directionality of functional lateralization for language.

Regarding the first of these points, if the similarity in L1 and L2 functional representation comes as a surprise, perhaps it is because many approaches to bilingual linguistic organization have assumed a functional separation between first and second language lexicons or linguistic systems in general. As we have seen earlier, this notion may have been reinforced by suggestions of differential language representation drawn from the lesion deficit literature, suggestions based on findings of differential impairment and recovery for first and second languages in bilinguals. Although it is acknowledged that evidence from brain-damaged populations is not an ideal basis from which to extrapolate to the neurologically healthy population, it has nevertheless been taken to be the final arbiter by some researchers. However, even within the aphasia literature, it has been argued that any notion of differential localization of the bilingual's languages is speculative at best, and unsupported by the majority of the cases observed. Moreover, the notion of separate functional representation of the bilinguals' two languages also has a strong following in the behavioral literature on bilingualism, quite independently of lesion data.

As Grosjean (1989) warned in his much-cited monograph, there is a danger of studying bilinguals as if they were “two monolinguals in one person” (p. 3). Grosjean criticized language researchers for expecting the two languages of bilinguals to operate independently of one another, rather than as a single, integrated system, where each language is used to the degree that is necessary for the communicative needs of the individual. Grosjean further proposes that an individual can choose either to keep both languages available (i.e., operate in a bilingual mode) or actively select one and deactivate the other (i.e., operate in a monolingual mode). For instance, when in the bilingual mode, the individual may readily substitute words and phrases from one language into a sentence spoken primarily in the other, or code-switch, with no disruption in the meaning or grammatical well-formedness of the sentence. Grosjean goes on to suggest that a full appreciation, and thus evaluation, of the complexity of language representation in the bilingual brain would require assessments in both the bilingual and the monolingual modes.

Grosjean's suggestion that the bilingual’s two languages must be stored and accessed together for semantically and syntactically appropriate code-switching to occur fits well with the present meta-analytic findings that the two languages of bilinguals are lateralized similarly for verbal tasks, even though very few of the laterality studies specifically involved switching between the languages.

Another recent perspective on bilingual language processing that is compatible with the our meta-analytic results of functional equivalence for L1 and L2 processing view encapsulated in the Bilingual Interactive Activation (BIA) model (Dijkstra, Van Heuven, & Grainger, 1998). The BIA model predicts that the two languages of bilinguals are represented very similarly, at least for bilinguals from related languages. Experimental evidence from primary studies in support of the BIA model is rapidly accumulating in findings of interference with target word recognition from both cross-language and within-language lexical competitors. These interference effects are widely taken to suggest that both languages must be active.

Consistent with Grosjean's view of bilinguals as being integrated users of their two languages, such that functioning in one language is not independent of functioning in the other, is evidence reviewed by Pavlenko and Scott (2002) for bi-directional transfer effects. Pavlenko and Scott point out that transfer from lexical and semantic information does not only proceed from the first to the second language, but can also proceed from the second language to the first, even in individuals with less proficiency in the second language (see also Helms-Park, 2001). This is consistent with our meta-analysis findings of a similarity in L1 and L2 laterality effects despite variations in L2 fluency. It also adds further support to the view of nonselective access, i.e., where both languages are thought to be activated during verbal processing in bilinguals, even when input and output are confined to a single language. Finally, the findings of the present research are inconsistent with models of bilingual lexical memory that postulate differential access to separate stores for the L1 and L2 lexicons (e.g. Kroll & Stewart, 1994).

The meta-analysis revealed that early onset of bilingualism (i.e., by the age of six) was associated with a reliably symmetrical pattern of hemispheric involvement in language that was significantly different from the LH dominance for language processing observed in bilinguals who acquired the L2 in later childhood or as adults. The finding of acquisition-age-related differences in lateralization lends support to something like a sensitive period of development during which the brain is especially modifiable by language input. Even allowing for individual variation in the mastery of later acquired languages, the present findings of a distinct pattern of language laterality for people who learned two languages very early in development relative to those who did not presents a compelling argument that there is something special for language development, or at least for its functional organization, during the first six years of life. The meta-analytic results are consistent with the findings of two previous bilingual meta-analyses with differing datasets which also found a less left lateralized pattern of brain functional organization of language in early bilinguals (Vaid & Hall, 1991; Hull & Vaid, 2002). This pattern of less left hemisphere dominance in early bilinguals (relative to monolinguals, or relative to late bilinguals) is remarkable, especially given that it was not expected. Early bilinguals had been expected to differ from late bilinguals, but not from monolinguals. Yet monolinguals and late bilinguals show LH dominance, while early bilinguals show more bilateral hemispheric involvement.

The present research found no support for other predictions in the bilingual laterality literature. Specifically, there was no support for suggestions of greater RH participation in fluent bilinguals, or for differences in lateralization for first vs. second languages, or for greater RH involvement for late bilinguals relative to those with early acquisition of the L2.

The findings of the present meta-analysis of the behavioral bilingual laterality literature could help bring the cognitive literature on bilingualism and the neuropsychological literature closer to an understanding of the variables that contribute to differential functional organization of the bilingual's languages. Most studies in the cognitive literature on bilingualism, and on which models of bilingual lexical processing have been based, have relied on late bilinguals, and few have sought to consider the influence of language acquisition history on the functional architecture of the bilingual mental lexicon. Given the meta-analysis findings that early bilinguals differed from late bilinguals in language lateralization patterns, it would be interesting in future cognitive studies to study processing differences between early and late bilinguals. Apart from its implications for the cognitive literature, the meta-analysis provides guidance in interpreting the bilingual laterality literature. It has shown that a variety of variables thought to be influential were not whereas other variables do appear to be operating, and in a consistent way, to influence language lateralization in bilinguals. At a more general level, the present research lends support to the view that bilingualism is not simply a variant of monolingualism but that it presents a unique array of experiential influences on brain organization of language. As such, it opens the way to deepening our understanding of the brain-language relationship.

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APPENDIX A

Data in the L1 Sample of Studies

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Bentin, S. (1981)[a]	He-En	32	0.50	0.00, 0.10	C	Nonfluent	Mixed	2	V	Limited	Unrelated
Chengappa et al. (2002)[b]	Kann-En	10	0.22	-0.66, 1.10	C	Fluent	Mixed	1	V	Submerged	Unrelated
Endo et al. (1981a)[a]	Ka-Ha	13	0.18	-0.59, 0.95	A	Nonfluent	Mixed	2	DT	Submerged	Related
Fabbro (1992, Exp. 2)[a]	It-Ge	3	0.75	-0.90, 2.41	A	Fluent	Women	7	DL	Submerged	Semirelated
Fabbro (1992, (Exp. 4)[a]											
Group 1	Fri-It	12	0.21	-0.29, 0.71	I	Fluent	Women	7	DT	Unspecified	Related
Group 2	Fri-It	12	0.08	-0.42, 0.58	I	Fluent	Women	7	DT	Unspecified	Related
Group 3	Fri-It	12	0.07	-0.43, 0.57	I	Fluent	Women	7	DT	Unspecified	Related
Fabbro (1992, Exp. 5)[a]	It-En	14	0.02	-0.72, 0.76	A	Fluent	Women	7	DT	Unspecified	Semirelated
Fabbro et al. (1991)[a]	It-En	36	0.17	-0.29, 0.63	A	Fluent	Women	7	DL	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Fabbro et al. (1990)[a]	It-En	14	0.15	-0.59, 0.89	A	Fluent	Women	8	DT	Unspecified	Semirelated
Fabbro et al. (1988)[b]											
Group 1	It-En	12	0.87	0.03, 1.71	A	Fluent	Women	1	DL	Submerged	Semirelated
Group 2	It-En	12	1.10	0.24, 1.95	A	Fluent	Women	1	DL	Submerged	Semirelated
Furtado & Webster (1991)[a]											
Group 3	En-Fr	16	1.03	0.30, 1.77	A	Fluent	Mixed	7	DT	Integrated	Semirelated
Green (1986)[a]											
Group 1	En-Sp	24	-0.08	-0.64, 0.49	A	Fluent	Men	7	DT	Submerged	Semirelated
Group 2	En-Sp	24	-0.20	-0.77, 0.36	A	Nonfluent	Men	7	DT	Submerged	Semirelated
Group 3	En-Sp	24	-0.28	-0.85, 0.29	A	Nonfluent	Men	7	DT	Submerged	Semirelated
Green et al. (1990)[a]											
Group 1	Sp-En	8	0.46	-0.54, 1.45	C	Fluent	Women	7	DT	Integrated	Semirelated
Group 2	Sp-En	8	0.48	-0.52, 1.47	C	Fluent	Men	7	DT	Integrated	Semirelated
Group 3	Sp-En	8	0.49	-0.51, 1.48	C	Fluent	Women	7	DT	Integrated	Semirelated
Group 4	Sp-En	8	0.37	-0.61, 1.36	C	Fluent	Men	7	DT	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Hall & Lambert (1988)[a]											
Group 1	En-Fr	16	-0.12	-0.82, 0.57	C	Fluent	Men	7	DT	Integrated	Semirelated
Group 2	En-Fr	16	0.26	-0.43, 0.96	C	Fluent	Men	7	DT	Integrated	Semirelated
Group 3	En-Fr	16	0.20	-0.49, 0.90	C	Nonfluent	Men	7	DT	Submerged	Semirelated
Hoosain & Shiu (1989)[a, d]	Ch-En	28	0.82	0.28, 1.37	C	Fluent	Mixed	1	V	Submerged	Unrelated
Ip & Hoosain (1993)[a]											
Group 1	Ch-En	9	0.31	-0.62, 1.24	C	Fluent	Women	1	DL	Submerged	Unrelated
Group 2	Ch-En	9	0.12	-0.80, 1.05	C	Fluent	Men	1	DL	Submerged	Unrelated
Jin, Y. (1988)[b]	Ha-En-Ch	24	1.08	0.48, 1.69	A	Fluent	Mixed	4	DL	Limited	Unrelated
Ke (1992)[a]											
Group 1	En-Ch	28	0.20	-0.33, 0.72	A	Fluent	Mixed	1	DL	Submerged	Unrelated
Group 2	En-Ch	29	0.77	0.24, 1.31	A	Nonfluent	Mixed	1	DL	Submerged	Unrelated
Magiste (1989)[a]											
Group 1		9	-0.22	-1.14, 0.71	C	Fluent	Men	7	V	Submerged	Semirelated
Group 2		9	-0.14	-1.07, 0.78	C	Fluent	Women	7	V	Submerged	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Magiste (1987)[a]											
Group 1	Ge-Sw	10	0.46	-0.42, 1.35	I	Fluent	Mixed	1	V	Integrated	Semirelated
Group 2	Ge-Sw	10	0.57	-0.33, 1.46	A	Fluent	Mixed	1	V	Integrated	Semirelated
Group 3	Po-Sw	14	0.70	-0.07, 1.46	A	Nonfluent	Mixed	1	V	Integrated	Semirelated
Manga & Sanchez (1989)[a]											
	En-Sp	31	0.54	0.03, 1.04	C	Fluent	Mixed	8	DT	Submerged	Semirelated
Rupp (1980)[b]	Vi-En	86	0.83	0.52, 1.14	C	Nonfluent	Mixed	1	DL	Limited	Unrelated
Sakhuja, T. (1990)[b]	Ur-En	120	0.12	-0.13, 0.38	I	Fluent	Mixed	5	DT	Submerged	Unrelated
Sewell & Panou (1983)[a, d]											
Group 1	En-Ge	6	0.46	-0.68, 1.61	A	Fluent	Men	1	V	Submerged	Semirelated
Group 2	En-Ge	6	0.61	-0.55, 1.76	A	Fluent	Women	1	V	Submerged	Semirelated
Group 3	En-Fr	6	0.24	-0.90, 1.37	I	Fluent	Men	1	V	Submerged	Semirelated
Group 4	En-Fr	6	0.16	-0.97, 1.30	I	Fluent	Women	1	V	Submerged	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Shanon (1982)[a]											
Group 1a	He-En	8	-0.02	-1.00, 0.96	A	Fluent	Men	1	V	Submerged	Unrelated
Group 1b	He-En	8	-0.03	-1.01, 0.95	A	Fluent	Women	1	V	Submerged	Unrelated
Group 2a	He-En	8	0.99	-0.79, 1.17	I	Fluent	Men	1	V	Submerged	Unrelated
Group 2b	He-En	8	0.28	-0.70, 1.27	I	Fluent	Women	1	V	Submerged	Unrelated
Group 3a	En-He	8	0.37	-0.62, 1.36	A	Fluent	Men	1	V	Integrated	Unrelated
Group 3b	En-He	8	0.31	-0.67, 1.30	A	Fluent	Women	1	V	Integrated	Unrelated
Simon (1984)[b]											
Group 1	Misc.	34	0.23	-0.25, 0.70	A	Fluent	Men	7	DT	Submerged	Semirelated
Group 2	Misc.	44	0.54	0.12, 0.97	A	Fluent	Women	7	DT	Submerged	Semirelated
Singh, M. (1990)[a]											
Group 1	Hi-En	18	-0.11	-0.77, 0.54	I	Fluent	Mixed	7	DT	Submerged	Unrelated
Group 2	Hi-En	18	-0.27	-0.92, 0.39	I	Fluent	Mixed	7	DT	Submerged	Unrelated
Soares (1984)[a]											
	Por-En	16	1.73	0.92, 2.55	A	Fluent	Men	7	DT	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Spiller-Bosatra et al. (1990)[a]											
Group 1	It-Ge	3	-0.53	-2.16, 1.09	I	Fluent	Women	1	DL	Submerged	Semirelated
Group 2	It-Ge	5	0.28	-0.96, 1.53	I	Fluent	Women	1	DL	Submerged	Semirelated
Starck et al. (1977)[a]	En-Fr-He	24	0.74	0.16, 1.33	I	Fluent	Mixed	1	DL	Integrated	Semirelated
Thomas (1987)[b]	Ch-En	26	0.09	-0.46, 0.63	A	Fluent	Mixed	1	DL	Integrated	Unrelated
Vaid (2002)[b]											
Group 1	Hi-En	16	-0.26	-0.96, 0.43	C	Fluent	Mixed	5	V	Integrated	Unrelated
Group 2	Ur-En	16	-0.35	-1.05, 0.35	C	Fluent	Mixed	5	V	Integrated	Unrelated
Vaid (2001)[b]											
Group 1	Sp-En	10	0.08	-0.80, 0.96	C	Fluent	Mixed	1	DT	Limited	Semirelated
Group 2	Sp-En	19	0.05	-0.59, 0.68	C	Fluent	Mixed	1	DT	Limited	Semirelated
Vaid (1999)[b]	Hi/Ur-En	10	00.61	-0.29, 1.50	I	Fluent	Mixed	5	V	Limited	Unrelated
Vaid (1988)[a]	Hi-En	20	0.08	-0.54, 0.70	C	Fluent	Mixed	5	V	Limited	Unrelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Vaid (1987)[a]											
Group 1	Fr-En	16	-0.10	-0.78, 0.59	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	Fr-En	16	0.18	-0.80, 1.16	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1984b)[b]											
Group 1	Fr-En	8	0.43	-0.56, 1.42	I	Fluent	Men	5	V	Integrated	Semirelated
Group 2	Fr-En	8	0.17	-0.81, 1.16	I	Fluent	Women	5	V	Integrated	Semirelated
Vaid (1984a; Exp. 1)[a]											
Group 1	En-Fr	4	-0.08	-1.46, 1.31	A	Fluent	Men	4	V	Integrated	Semirelated
Group 2	En-Fr	4	-0.73	-2.17, 0.70	A	Fluent	Women	4	V	Integrated	Semirelated
Group 3	Fr-En	4	-0.03	-1.42, 1.35	A	Fluent	Men	4	V	Integrated	Semirelated
Group 4	Fr-En	4	-0.11	-1.50, 1.27	A	Fluent	Women	4	V	Integrated	Semirelated
Group 5	En-Fr	8	-0.23	-1.21, 0.76	I	Fluent	Men	4	V	Integrated	Semirelated
Group 6	En-Fr	8	-0.44	-1.43, 0.56	I	Fluent	Women	4	V	Integrated	Semirelated
Vaid (1984a; Exp. 2)[a]	En-Fr	16	0.14	-0.54, 0.85	I	Fluent	Mixed	3	V	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Vaid (1984a; Exp. 3)[a]											
Group 1	En-Fr	8	-0.36	-1.35, 0.62	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	En-Fr	4	0.12	-1.27, 1.50	A	Fluent	Mixed	5	V	Integrated	Semirelated
Group 3	Fr-En	4	-0.23	-1.62, 1.16	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1981b)[b]											
Group 1	En-Fr	8	0.06	-0.92, 1.04	I	Fluent	Mixed	3	V	Integrated	Semirelated
Group 2	Fr-En	8	0.41	-0.51, 1.40	A	Fluent	Mixed	3	V	Integrated	Semirelated
Vaid (1981a)[b]											
Group 1	En-Fr	8	0.17	-0.81, 1.15	I	Fluent	Mixed	3	V	Integrated	Semirelated
Group 2	Fr-En	4	0.30	-1.10, 1.69	A	Fluent	Mixed	3	V	Integrated	Semirelated
Group 3	En-Fr	4	-0.02	-1.40, 1.37	A	Fluent	Mixed	3	V	Integrated	Semirelated
Vaid (1980c)[b]											
Group 1	Hi-En	8	0.69	-0.32, 1.70	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	Fr-En	8	-0.72	-1.93, 0.30	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1980b)[b]											
Group 1	Fr-En	16	-0.02	-0.71, 0.68	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	Fr-En	8	0.09	-0.89, 1.07	A	Fluent	Mixed	5	V	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Vaid (1980a)[b]											
Group 1	En-Fr	8	-0.95	-1.99, 0.08	I	Fluent	Men	3	V	Integrated	Semirelated
Group 2	En-Fr	8	-0.01	-0.99, 0.97	I	Fluent	Women	3	V	Integrated	Semirelated
Group 3	Fr-En	4	0.15	-1.24, 1.53	A	Fluent	Men	3	V	Integrated	Semirelated
Group 4	Fr-En	4	0.12	-1.27, 1.50	A	Fluent	Women	3	V	Integrated	Semirelated
Group 5	En-Fr	4	-0.12	-1.51, 1.27	A	Fluent	Men	3	V	Integrated	Semirelated
Group 6	En-Fr	4	-0.02	-1.40, 1.37	A	Fluent	Men	3	V	Integrated	Semirelated
Vaid & Frenck-Mestre (2002)[a]	Fr-En	16	-0.01	-0.71, 0.68	A	Fluent	Mixed	4	V	Integrated	Semirelated
Vaid & Frenck-Mestre (1990)[b]											
Group 1	Sp-En	8	-0.11	-1.09, 0.87	I	Fluent	Mixed	4	V	Submerged	Semirelated
Group 2	Sp-En	8	0.03	-0.95, 1.01	I	Fluent	Mixed	4	V	Submerged	Semirelated
Vaid & Park (1997)[a]	Ha-En	16	1.11	0.41, 1.81	A	Fluent	Mixed	3	V	Integrated	Unrelated
Voyer et al. (2002)[b]											
Group 1	En-Fr	15	0.62	-0.11, 0.35	C	Fluent	Mixed	5	DL	Integrated	Semirelated
Group 2	Fr-En	15	1.01	0.25, 1.77	C	Fluent	Mixed	5	DL	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L1 context	Linguistic relatedness
Wesche & Schneiderman (Exp. 1, 1982)[a]	En-Fr	61	0.46	0.10, 0.82	A	Nonfluent	Mixed	1	DL	Integrated	Semirelated
Wesche & Schneiderman (Exp. 2, 1982)[a]	Fr-En	37	-0.03	-0.48, 0.43	A	Nonfluent	Mixed	1	DL	Integrated	Semirelated

Note. CI = confidence interval; Exp. = experiment; DL = DL listening; DT = dual task/manual-verbal interference; V = tachistoscopic viewing/lateralized viewing; I = infancy; C = childhood; A = post-childhood. Effect sizes (ds) are positive when left hemisphere activation is greater relative to right hemisphere activation and negative when right hemisphere activation is greater relative to left hemisphere activation. [a] Published study. [b] Unpublished study. [c] Data from digit span task were omitted, as this was considered a nonverbal task. [d] Data from dot localization task were omitted, as this was considered a nonverbal task.

Verbal task demands key.

1 = vocalized word/letter naming
2 = nonvocalized word/letter identification
3 = word pair phonetic judgments
4 = word pair orthographic judgments
5 = word pair semantic judgments
6 = word pair syntactic judgments
7 = whole-language comprehension

Language abbreviations key.

En = English
Fr = French
Ma = Mandarin
Ru = Russian
Ja = Japanese
Fi = Finnish
Kann = Kannada
Ha = Harean
Sw = Swedish
Por = Portuguese
Ur = Urdu
Tu = Turkey
Na = Navajo

Sp = Spanish
Ch = Chinese
Ge = German
Ca = Catalan
It = Italian
He = Hebrew
Ka = Kanji
Fri = Friulan
Po = Polish
Vi = Vietnamese
Hi = Hindi
Ja = Japanese
To = Tok Pisin

APPENDIX B

Data in L2 sample of studies

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi- mental paradigm	L2 context	Linguistic relatedness
Albanese, J. (1985)[a]											
Group 1	En-Fr	10	-0.22	-1.04, 0.66	I	Fluent	Mixed	1	DL	Integrated	Semirelated
Group 2	En-Fr	10	0.59	-0.30, 1.49	A	Fluent	Mixed	1	DL	Integrated	Semirelated
Bentin, S. (1981)[a]	He-En	32	0.50	0.00, 0.10	C	Nonfluent	Mixed	2	V	Submerged	Unrelated
Chengappa et al. (2002)[b]	Kann-En	10	-0.38	-1.26, 0.50	C	Fluent	Mixed	1	V	Limited	Unrelated
Endo et al. (1981b)[a]	Ja-Ha	18	0.20	-0.45, 0.86	A	Nonfluent	Mixed	2	V	Limited	Related
Endo et al. (1981a)[a]	Ka-Ha	13	0.47	-0.31, 1.25	A	Nonfluent	Mixed	2	DL	Limited	Related
Fabbro (1992, Exp. 2)[a]	It-Ge	3	1.00	-0.69, 2.70	A	Fluent	Women	7	DL	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Fabbro (1992, Exp. 4)[a]											
Group 1	Fri-It	12	0.17	-0.63, 0.97	I	Fluent	Women	7	DL	Unspecified	Related
Group 2	Fri-It	12	0.08	-0.72, 0.88	I	Fluent	Women	7	DL	Unspecified	Related
Group 3	Fri-It	12	-0.03	-0.83, 0.77	I	Fluent	Women	7	DL	Unspecified	Related
Fabbro (1992, Exp. 5)[a]	It-En	14	0.02	-0.72, 0.76	A	Fluent	Women	7	DL	Unspecified	Semirelated
Fabbro et al. (1990)[a]	It-En	14	0.63	-0.13, 1.40	A	Fluent	Women	8	DL	Unspecified	Semirelated
Fabbro et al. (1987)[a]											
Group 1	It-En	12	0.81	-0.02, 1.64	A	Fluent	Women	1	DL	Limited	Semirelated
Group 2	It-En	12	0.42	-0.39, 1.23	A	Fluent	Women	1	DL	Limited	Semirelated
Furtado & Webster (1991)[a]											
Group 1	En-Fr	16	1.05	0.31, 1.79	I	Fluent	Mixed	7	DL	Integrated	Semirelated
Group 2	Fr-En	16	0.62	-0.09, 1.33	A	Fluent	Mixed	7	DL	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Green (1986)[a]											
Group 1	En-Sp	24	0.06	-0.51, 0.62	A	Fluent	Men	7	DL	Limited	Semirelated
Group 2	En-Sp	24	-0.25	-0.82, 0.31	A	Nonfluent	Men	7	DL	Limited	Semirelated
Group 3	En-Sp	24	0.00	-0.57, 0.57	A	Nonfluent	Men	7	DL	Limited	Semirelated
Green et al. (1990)[a]											
Group 1	Sp-En	8	0.40	-0.59, 1.39	C	Fluent	Women	7	DL	Submerged	Semirelated
Group 2	Sp-En	8	0.19	-0.79, 1.18	C	Fluent	Men	7	DL	Submerged	Semirelated
Group 3	Sp-En	8	1.11	0.05, 2.16	C	Fluent	Women	7	DL	Submerged	Semirelated
Group 4	Sp-En	8	0.53	-0.47, 1.53	C	Fluent	Men	7	DL	Submerged	Semirelated
Hall & Lambert (1988)[a]											
Group 1	En-Fr	16	0.19	-0.50, 0.89	C	Fluent	Men	7	DL	Submerged	Semirelated
Group 2	En-Fr	16	0.22	-0.48, 0.91	C	Fluent	Men	7	DL	Integrated	Semirelated
Group 3	En-Fr	16	0.24	-0.46, 0.93	C	Nonfluent	Men	7	DL	Limited	Semirelated
Hatta (1982)[b]	Ja-En	20	0.55	-0.08, 1.18	A	Nonfluent	Mixed	2	DL	Limited	Unrelated
Hausmann et al. (2001)[b]	Ge-Tu	17	0.16	-0.52, 0.83	I	Fluent	Mixed	5	V	Submerged	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Hoosain & Shiu (1989)[a, d]	Ch-En	28	0.38	-0.15, 0.91	C	Fluent	Mixed	1	V	Integrated	Unrelated
Ip & Hoosain (1993)[a]											
Group 1	Ch-En	9	0.41	-0.52, 1.34	C	Fluent	Women	1	DL	Limited	Unrelated
Group 2	Ch-En	9	0.26	-0.67, 1.18	C	Fluent	Men	1	DL	Limited	Unrelated
Jin, Y. (1988)[b]											
Group 1	Ha-En-Ch	24	0.79	0.21, 1.38	A	Fluent	Mixed	4	V	Submerged	Unrelated
Group 2	Ha-En-Ch	24	-0.67	-1.25, -.09	A	Nonfluent	Mixed	4	V	Submerged	Semirelated
Kang (1984)[b]	Misc.-En	40	0.68	0.23, 1.13	A	Fluent	Mixed	2	DL	Submerged	Mixed
Ke (1992)[a]											
Group 1	En-Ch	28	0.31	-0.22, 0.84	A	Fluent	Mixed	1	DL	Limited	Unrelated
Kilborn (2002)[b]											
Group 1	Ur-En	20	0.02	-0.34, 0.38	I	Fluent	Mixed	1	V	Submerged	Unrelated
Group 2	Ur-En	20	-0.05	-0.41, 0.31	A	Fluent	Mixed	1	V	Submerged	Unrelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Magiste, E. (1989)[a]											
Group 1		9	-0.29	-1.21, 0.64	C	Fluent	Men	7	V	Submerged	Semirelated
Group 2		9	-0.16	-1.08, 0.77	C	Fluent	Women	7	V	Submerged	Semirelated
Magiste (1987)[a]											
Group 1	Ge-Sw	10	0.41	-0.48, 1.29	I	Fluent	Mixed	1	V	Submerged	Semirelated
Group 2	Ge-Sw	10	0.35	-0.53, 1.23	A	Fluent	Mixed	1	V	Submerged	Semirelated
Group 3	Po-Sw	14	-0.07	-0.81, 0.67	A	Nonfluent	Mixed	1	V	Submerged	Semirelated
Manga & Sanchez (1989)[a]	En-Sp	31	0.38	-0.12, 0.87	C	Fluent	Mixed	8	DL	Limited	Semirelated
Rastatter & Scukanek (1990)[a]	Ch-En	16	0.35	-0.35, 1.05	C	Fluent	Mixed	1	1	Submerged	Unrelated
Sewell & Panou (1983)[a, d]											
Group 1	En-Ge	6	0.22	-0.91, 1.36	A	Fluent	Men	1	V	Submerged	Semirelated
Group 2	En-Ge	6	0.45	-0.70, 1.59	A	Fluent	Women	1	V	Submerged	Semirelated
Group 3	En-Fr	6	0.14	-0.99, 1.28	I	Fluent	Men	1	V	Submerged	Semirelated
Group 4	En-Fr	6	0.21	-0.93, 1.34	I	Fluent	Women	1	V	Submerged	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Shanon (1982)[a]											
Group 1a	He-En	8	-0.17	-1.15, 0.81	A	Fluent	Men	1	V	Integrated	Unrelated
Group 1b	He-En	8	-0.23	-1.22, 0.75	A	Fluent	Women	1	V	Integrated	Unrelated
Group 2a	He-En	8	0.70	-0.31, 1.71	I	Fluent	Men	1	V	Integrated	Unrelated
Group 2b	He-En	8	0.35	-0.64, 1.33	I	Fluent	Women	1	V	Integrated	Unrelated
Group 3a	En-He	8	0.22	0.76, 1.20	A	Fluent	Men	1	V	Submerged	Unrelated
Group 3b	En-He	8	-0.31	-1.30, 0.67	A	Fluent	Women	1	V	Submerged	Unrelated
Spiller-Bosatra et al. (1990)[a]											
Group 1	It-Ge	3	-0.47	-2.09, 1.15	I	Fluent	Women	1	DL	Integrated	Semirelated
Group 2	It-Ge	5	-0.02	-1.26, 1.22	I	Fluent	Women	1	DL	Integrated	Semirelated
Thomas (1987)[b]	Ch-En	26	0.20	-0.34, 0.75	A	Fluent	Mixed	1	DL	Submerged	Unrelated
Vaid (2002)[b]											
Group 1	Hi-En	16	-0.14	-0.84, 0.55	C	Fluent	Mixed	5	V	Submerged	Unrelated
Group 2	Ur-En	16	-0.08	-0.77, 0.61	C	Fluent	Mixed	5	V	Submerged	Unrelated
Vaid (2001)[b]											
Group 1	Sp-En	10	0.20	-0.68, 1.07	C	Fluent	Mixed	1	DL	Submerged	Semirelated
Group 2	Sp-En	19	0.05	-0.59, 0.69	C	Fluent	Mixed	1	DL	Submerged	Semirelated
Vaid (1999)[b]	Hi-En	10	0.41	-0.47, 1.30	I	Fluent	Mixed	5	V	Submerged	Unrelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Vaid (1984a; Exp. 1)[a]											
Group 1	En-Fr	4	-0.03	-1.41, 1.36	A	Fluent	Men	4	V	Integrated	Semirelated
Group 2	En-Fr	4	0.09	-1.30, 1.47	A	Fluent	Women	4	V	Integrated	Semirelated
Group 3	Fr-En	4	0.06	-1.33, 1.45	A	Fluent	Men	4	V	Integrated	Semirelated
Group 4	Fr-En	4	-0.30	-1.69, 1.10	A	Fluent	Women	4	V	Integrated	Semirelated
Group 5	En-Fr	8	-0.43	-1.42, 0.57	I	Fluent	Men	4	V	Integrated	Semirelated
Group 6	En-Fr	8	-0.10	-1.08, 0.89	I	Fluent	Women	4	V	Integrated	Semirelated
Vaid (1984a; Exp. 3)[a]											
Group 1	En-Fr	8	-0.21	-1.19, 0.78	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	En-Fr	4	0.27	-1.12, 1.66	A	Fluent	Mixed	5	V	Integrated	Semirelated
Group 3	Fr-En	4	-0.01	-1.39, 1.38	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1981b)[b]											
Group 1	Fr-En	8	0.45	-0.55, 1.44	I	Fluent	Mixed	3	V	Integrated	Semirelated
Group 2	Fr-En	8	0.68	-0.33, 1.69	A	Fluent	Mixed	3	V	Integrated	Semirelated
Vaid (1981a)[b]											
Group 1	En-Fr	8	0.20	-0.78, 1.19	I	Fluent	Mixed	3	V	Integrated	Semirelated
Group 2	Fr-En	4	-0.17	-1.56, 1.22	A	Fluent	Mixed	3	V	Integrated	Semirelated
Group 3	En-Fr	4	0.20	-1.19, 1.59	A	Fluent	Mixed	3	V	Integrated	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Vaid (1980c)[b]											
Group 1	Fr-En	8	-0.42	-1.41, 0.57	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	Fr-En	8	-0.15	-1.13, 0.83	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1980b)[b]											
Group 1	Fr-En	16	0.00	-0.69, 0.70	I	Fluent	Mixed	5	V	Integrated	Semirelated
Group 2	Fr-En	4	-0.72	-1.93, 0.30	A	Fluent	Mixed	5	V	Integrated	Semirelated
Vaid (1980a)[b]											
Group 1	En-Fr	8	-0.24	-1.22, 0.74	I	Fluent	Men	3	V	Integrated	Semirelated
Group 2	En-Fr	8	-0.23	-1.21, 0.76	I	Fluent	Women	3	V	Integrated	Semirelated
Group 3	Fr-En	4	0.34	-1.06, 1.74	A	Fluent	Men	3	V	Integrated	Semirelated
Group 4	Fr-En	4	0.14	-1.25, 1.52	A	Fluent	Women	3	V	Integrated	Semirelated
Group 5	En-Fr	4	-0.12	-1.51, 1.27	A	Fluent	Men	3	V	Integrated	Semirelated
Group 6	En-Fr	4	-0.02	-1.40, 1.37	A	Fluent	Men	3	V	Integrated	Semirelated
Vaid & Frenck-Mestre (2002)[a]	Fr-En	16	-0.02	-0.72, 0.67	A	Fluent	Mixed	4	V	Submerged	Semirelated
Vaid & Frenck-Mestre (1990)[b]											
Group 1	Sp-En	8	0.07	-0.91, 1.05	I	Fluent	Mixed	4	V	Submerged	Semirelated
Group 2	Sp-En	8	-0.15	-1.16, 0.81	I	Fluent	Mixed	4	V	Submerged	Semirelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Vaid & Lambert (1979)[a]											
Group 1	Fr-En	8	-0.03	-1.01, 0.95	I	Fluent	Women	5	V	Integrated	Semirelated
Group 2	Fr-En	8	0.09	-0.89, 1.07	I	Fluent	Men	5	V	Integrated	Semirelated
Voyer et al. (2002)[b]											
Group 1	En-Fr	15	0.74	-0.00, 1.48	C	Fluent	Mixed	5	DL	Integrated	Semirelated
Group 2	Fr-En	15	0.80	0.06, 1.55	C	Fluent	Mixed	5	DL	Integrated	Semirelated
Wesche & Schneiderman (Exp. 1, 1982)[a]	En-Fr	61	0.17	-0.18, 0.53	A	Nonfluent	Mixed	1	DL	Integrated	Semirelated
Wesche & Schneiderman (Exp. 2, 1982)[a]	Fr-En	37	0.81	0.34, 1.28	A	Nonfluent	Mixed	1	DL	Integrated	Semirelated
Winfield, F. (1984)[b]	Na-En	78	0.40	0.08, 0.72	C	Fluent	Mixed	5	DL	Integrated	Unrelated

Study author(s), year	L1-L2	Group n	d	95% CI	Age of L2 onset	L2 fluency	Sex	Task demands	Experi-mental paradigm	L2 context	Linguistic relatedness
Wuillemin et al. (Exp. 1, 1994)[a]											
Group 1	To-En	12	0.59	-0.23, 1.40	I	Nonfluent	Mixed	1	V	Limited	Unrelated
Group 2	To-En	12	0.56	-0.25, 1.38	I	Nonfluent	Mixed	1	V	Limited	Unrelated
Yoshizaki & Hatta (1987)[a]											
Group 1	Ja-He	7	0.70	-0.38, 1.77	A	Nonfluent	Mixed	2	V	Limited	Semirelated
Group 2	Ja-He	7	0.28	-0.77, 1.34	A	Nonfluent	Mixed	2	V	Limited	Semirelated
Group 3	Ja-He	7	0.88	-0.22, 1.98	A	Nonfluent	Mixed	2	V	Limited	Semirelated

Note. CI = confidence interval; Exp. = experiment; DL = DL listening; DT = dual task/manual-verbal interference; V = tachistoscopic viewing/lateralized viewing; I = infancy; C = childhood; A = post-childhood. Effect sizes (ds) are positive when left hemisphere activation is greater relative to right hemisphere activation and negative when right hemisphere activation is greater relative to left hemisphere activation. [a] Published study. [b] Unpublished study. [c] Data from digit span task were omitted, as this was considered a nonverbal task. [d] Data from dot localization task were omitted, as this was considered a nonverbal task.

Verbal task demands key.

1 = vocalized word/letter naming
2 = nonvocalized word/letter identification
3 = word pair phonetic judgments
4 = word pair orthographic judgments
5 = word pair semantic judgments
6 = word pair syntactic judgments
7 = whole-language comprehension

Language abbreviations key.

En = English
Fr = French
Ma = Mandarin
Ru = Russian
Ja = Japanese
Fi = Finnish
Kann = Kannada
Ha = Harean
Sw = Swedish
Por = Portuguese
Ur = Urdu
Tu = Turkey
Na = Navajo
Sp = Spanish
Ch = Chinese
Ge = German
Ca = Catalan
It = Italian
He = Hebrew
Ka = Kanji
Fri = Friulan
Po = Polish
Vi = Vietnamese
Hi = Hindi
Ja = Japanese
To = Tok Pisin

APPENDIX C

Comparison levels with remaining unexplained variance

Moderator$^{a, b}$	k	Total sample size n	Sample-weighted mean d	95% CI	Mean unweighted d	Homogeneity statistic Q_b	% Variance explained by sampling error^{c}
Combined sex dataset for L1 partitioned by L2 acquisition age							
Childhood	17	398	0.49	0.34, 0.63	0.37	30.98*	69
Unrelated L1 - L2 linguistic structure dataset for L1 partitioned by L2 acquisition age							
Infancy	7	110	0.12	-0.15, 0.38	0.22	4.29	97
Childhood	10	254	0.52	0.34, 0.70	0.33	22.19*	76
Adolescence	9	155	0.18	0.26, 0.71	0.43	12.97	95
Unrelated L1 - L2 linguistic structure dataset for L1 partitioned by L2 fluency							
Fluent	22	362	0.30	0.10, 0.45	0.29	35.09*	73
Nonfluent	4	157	0.71	0.48, 0.94	0.68	2.49	97
Unrelated L1 - L2 linguistic structure dataset for L1 partitioned by paradigm							
Dichotic listening	6		0.55	0.34, 0.76		9.32	88
Dual task	4		0.23	-0.04, 0.51		11.37*	72
Unrelated L1 - L2 linguistic structure dataset for L1 partitioned by participant sex							
Men	4		0.16	-0.32, 0.65		0.31	98
Women	4		0.22	-0.26, 0.70		0.34	98
Mixed	18		0.46	0.32, 0.59		43.31*	71
Combined sex dataset for L1 partitioned by L2 acquisition age^{c}							
Infancy	12	168	0.05	-0.16, 0.27	0.08	6.09	91
Childhood	17	398	0.49	0.34, 0.63	0.37	30.98*	59
Adolescence	19	330	0.41	0.25, 0.57	0.37	22.64	89

Note. *p<.05, df = k-1; k = number of independent effect sizes; CI = confidence interval. Positive effect sizes (ds) reflect greater activation in the left hemisphere when the CIs do not include zero, and bilateral activation when the CIs include zero. [a] Two outliers with sample-adjusted meta-analytic deviancy (SAMD) scores greater than five were removed from the L1 analyses. [b] Six outliers with sample-adjusted meta-analytic deviancy (SAMD) scores greater than four were removed from the L2 analyses.

[c] Following Arthur et al. (2001), samples of studies for which 85% or more variance was explained by sampling error were considered homogeneous with respect to effect sizes.

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