Simultaneous and Sequential Bilinguals: Cross domain benefits as measured by behaviour and resting-state functional magnetic resonance imaging.

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I. Abstract

The aim of the present investigation is to explore differences in the bilingual language learning experience based on age of second language acquisition, which fundamentally shapes the way language is represented in the brain and the abilities of the speaker. The question asked here is whether there is a "simultaneous bilingual advantage" when learning a new foreign language due to the attainment of two languages within a highly sensitive period in brain development, and whether there is transfer of any advantage to the music domain. Two groups of bilinguals were compared: 10 simultaneous bilinguals, who learnt both English and French from birth, and 11 sequential bilinguals, who learnt French from birth and English after the age of 7 years. All were highly proficient in both English and French, had no experience in a third language, nor exposure to the languages used in the experiment, and participants had no musical training. Participants were tested on new foreign speech perception and production tasks in Hindi and Farsi and were tested on comparable music perception and production tasks. They also completed a resting-state functional magnetic imaging scan to investigate intrinsic functional brain connectivity networks.

Whereas the simultaneous bilinguals significantly outperformed their late-trained counterparts on the foreign speech perception task, the discrimination of the Hindi dental retroflex contrast, the two groups did not differ on the foreign speech production tasks (Hindi and Farsi), or music production tasks, and the sequential bilinguals performed significantly better on a music perception task. The results suggest that the advantage observed behaviorally in the simultaneous compared to the sequential bilinguals is confined to speech perception, and that simultaneous and sequential bilingualism might have different effects on auditory perception abilities as a result of

different language acquisition circumstances. In addition, using the behavioural score on the Hindi discrimination task, simultaneous bilinguals who showed better performance on the task also displayed greater brain functional connectivity between the left temporoparietal junction and the right planum temporale, and between right Heschl's gyrus and the left supramarginal gyrus.

Both the behavioural and imaging results suggest that linguistic experiences during the first year of life, when brain circuitry is undergoing crucial development, impact language perceptual learning abilities and brain functional organization. Simultaneous acquisition of two languages appears to confer an advantage later in life for perceiving the sounds of a new foreign language. In the larger context, this study adds to the body of knowledge about second language acquisition, its impact on behaviour and the brain, and the findings could have implications for language education.

II. Résumé

Le but de cette étude est d'explorer les différentes expériences d'apprentissage bilingue du langage en lien avec l'âge d'acquisition de la deuxième langue, qui a une influence fondamentale sur la manière dont le langage est représenté dans le cerveau, ainsi que les capacités linguistiques d'un individu. La question posée ici est si les bilingues simultanés sont avantagés lors de l'apprentissage d'une deuxième langue, car ils ont acquis deux langues lors d'une période de développement cérébral très sensible, et si cet avantage peut être transféré au domaine musical. Deux groupes de bilingues ont été comparés: 10 bilingues simultanés, ayant appris l'anglais et le français depuis la naissance, et 11 bilingues séquentiels, ayant appris le français depuis la naissance et l'anglais après l'âge de 7 ans. Tous les participants étaient extrêmement compétents en anglais et en français, n'avaient aucune expérience dans une troisième langue ni dans les langues utilisées pour cette étude, et n'avaient aucune expérience musicale. Nous avons testé la perception et la production de sons en langue étrangère (hindi et farsi) chez ces participants, ainsi que la perception et la production musicale dans des tâches comparables aux tâches linguistiques. Les participants ont aussi complété des scans d'imagerie par résonnance magnétique fonctionnelle au repos pour que l'on puisse regarder les réseaux de connectivité fonctionnelle cérébrale.

Tandis que les bilingues simultanés ont surpassé de manière significative les bilingues séquentiels sur la tâche de production de discours étranger (discrimination du contraste dentaire rétroflexe hindi), il n'y avait pas de différence entre les deux groupes en terme de production de discours étranger (hindi et farsi), ou dans les tâches de production de musique, et les bilingues séquentiels ont significativement mieux réussi la tâche de perception musicale. Ces résultats

suggèrent que l'avantage observé chez les bilingues simultanés par rapport aux bilingues séquentiels est réservé à la perception du discours, et que le bilinguisme simultané et séquentiel peuvent avoir des effets différents sur les capacités de perception auditive dû aux différentes circonstances d'acquisition du langage. De plus, en regardant la performance sur la tâche de discrimination hindi, les bilingues simultanés ayant mieux réussi la tâche ont aussi démontré une plus grande connectivité fonctionnelle cérébrale entre la jonction tempoparietale gauche et le planum temporale droit, et entre le gyrus d'Heschl droit et le gyrus surpamarginal gauche.

Les résultats comportementaux ainsi que les résultats d'imagerie cérébrale indiquent que les expériences linguistiques pendant la première année de vie, quand la circuiterie cérébrale subit des développements cruciaux, ont un impact sur les capacités d'apprentissage perceptuel du langage et sur l'organisation fonctionnelle du cerveau. L'acquisition simultanée de deux langues semble conférer un avantage plus tard dans la vie pour la perception de nouveaux sons dans une langue étrangère. Dans un contexte plus large, cette étude ajoute aux connaissances sur l'acquisition d'une deuxième langue, son impact sur le comportement et le cerveau, et les résultats pourraient avoir des implications pour l'enseignement des langues.

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IV. Preface and Contribution of Authors

Lucía Vaquero (PhD) [a,c], Shari Baum (PhD) [b,c], Virginia Penhune (PhD) [a,c,d], and Denise Klein (PhD) [c,e] designed the study. Participant Testing and data collection was done by Lucía Vaquero, Paul Noel Rousseau [a,c,d,e,f] , Diana Vozian [a], and Desiree D'Souza [c,e,f]. All material appearing in this document was written by Desiree D'Souza. Figures were designed and created by Lucía Vaquero and Desiree D'Souza.

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Chapter 1. Introduction

The age of acquisition of critical skills, such as learning a second language and learning to play a musical instrument, has been said to be constrained by sensitive periods (Penfield and Roberts, 1959; Ruben et al., 1997; Werker and Tees, 2005; Fox et al., 2010; Penhune, 2011). That is, there is likely an optimal age for learning these skills in order to confer specific language, music, and cognitive advantages to a person. For example, early acquisition of a second language results in more native-like articulation when compared to later learning, and is linked to changes in brain structure in regions commonly associated with articulation, such as the left basal ganglia (Berken et al., 2016). Simultaneous bilinguals, who learn two languages from birth, also show differences in brain structure (Berken et al., 2015) in the left anterior insula region together with enhanced neural efficiency in performing overt language tasks when compared to bilinguals who acquire their second language after the age of 7 years (Berken et al., 2016). Moreover, early bilinguals have been shown to learn the phonetics of a third language more easily than late bilinguals (Cenoz, 2003).

Whereas bilingual participants are often grouped into one category, bilinguals can learn language simultaneously or sequentially, and age of acquisition fundamentally shapes bilingual experience and resulting brain networks (Hernandez and Li, 2007; Berken et al., 2015; Berken et al., 2016). As will be discussed later, since the two languages of the bilingual can be learnt simultaneously from birth or sequentially, with a second language being learnt after already establishing a first, investigating the differences between bilinguals based on their age of acquisition could provide improved insights about the bilingual brain and shed light on how experience shapes the brain.

Since language and music skills share several key functions including the need for perception, integration of auditory and motor feedback, sound production, and the neuro-anatomical overlap of the regions involved in carrying out these functions, some have suggested that there might be transfer of music skills to language and vice versa, (Zatorre et al., 2002; Moreno et al., 2009; Besson et al., 2011; Patel 2014). Recently, it has been shown that music training and bilingual skills can transfer to other cognitive domains (Kraus et al., 2007; Bialystok, 2011; Gerry et al., 2012; Moreno, 2009; Kraus et al., 2010; Besson et al., 2011). Thus, it is conceivable that advantages gained by extensive skill in language learning, such as bilingualism, may transfer to the music domain and vice versa (Vaquero et al., 2016a). The present investigation focuses on the examination of whether simultaneous bilinguals might show advantages over sequential bilinguals on a range of language and/or music tasks, and whether these group differences would be correlated with brain connectivity patterns. We hypothesized that simultaneous bilinguals would outperform sequential bilinguals on specific language, music, and cognitive tasks, and would show differences in brain connectivity that related to the behavioural results. This sub-study for the Master's thesis formed part of a larger project that compares early and late bilinguals, and early- and late-trained musicians on language, music, and specific cognitive tasks, in order to look at sensitive period effects and transfer between language and music.

Chapter 2. Literature Review

2.1 Bilingualism

Bilingualism is the ability to communicate fluently in two languages, allowing the speaker to expand the people and cultures they are able to communicate with, and, in a sense, expand their world (Canadian Encyclopedia, 2006). Bilingualism is of particular importance to Canadians as our country has two official languages, English and French. In the 2011 census, 5.8 million people nationwide reported the ability to communicate in both English and French, which corresponds to a bilingualism rate of 17.5%, and an increase over the last 50 years that corresponds to a growth rate of around 160% (Statistics Canada, 2011). The 2011 census also reported that Montreal, which has been a multilingual hub since its founding, has the highest rate of bilingualism in the country (Statistics Canada, 2011).

Bilingualism is currently viewed as a positive force, conferring both educational and career benefits, but for the first half of the century it was viewed negatively, with researchers claiming that it hurt children's I.Q. and disadvantaged verbal development (Darcy, 1951). This view has long since shifted, and the reverse has been proposed, that is, that there is a "bilingual advantage" (Peal and Lambert, 1962; Bialystok et al., 2004a). Bilinguals are thought to have better executive function and cognitive control abilities, and better performance on sustained attention and switching tasks, as compared to monolinguals (Bialystok et al., 2004a; Costa et al., 2008; Bialystok et al., 2008; Prior et al., 2010). Bilingualism has also been reported to be advantageous for the aging brain, providing protection against cognitive decline. Bilingual adults seem to resist the effects of dementia better than their monolingual peers, delaying onset of symptoms for 4.3 years

(Bialystok et al., 2007), although other studies have shown that multilingualism delays the onset of Alzheimer's disease, with the factors that contribute to the advantage still unknown (Chertkow et al., 2010). Given that bilingualism is unique among complex skills in that it can be acquired from birth, when brain circuitry is being developed, and also much later in life, when the brain circuitry subserving the first language is already well developed (Berken et al., 2016), it is an optimal model for studying how early and late language acquisition affects brain organization, something explored in the current thesis.

2.2 Age of Acquisition

Age of acquisition refers to the age at which a language is learnt. The first language is acquired from birth and is thus called L1. A second language is generally learnt following acquisition of an L1, and is thus called L2 (Perani et al., 1998). Although, as noted earlier, bilinguals are generally thought of as one group and in many studies are treated as a homogeneous sample, there are behavioural (e.g. such as cognitive control) and neural differences, (e.g. cortical thickness, interhemispheric functional connectivity), between bilingual groups, based on the age at which they acquired their first and second languages (Klein et al., 1994; Lehtonen et al., 2012; Klein et al., 2013; Berken et al., 2016a; Berken et al., 2016b; Fernández-Coello et al., 2016; Barbeau et al., 2017; Kousaie et al., 2017). The term *simultaneous bilingual* (De Houwer, 1996; Berken et al., 2016) refers to people who learnt two languages at the same time from birth; thus these people have two L1s. The term *sequential bilingual* refers to people who learnt one language from birth, and the second language at a time following that (Flynn et al., 2005; Berken et al., 2016). Depending on the age of acquisition of the L2, the terms *early sequential bilingual*, and *late sequential bilingual* are applied (Klein et al., 2014). For this study, those who learnt their L2 after the age of 7 years were classified as sequential bilinguals.

By comparing simultaneous bilinguals to sequential bilinguals, the study aimed to examine these two groups with different language learning experience, to determine the impact of this experience on brain organization and behaviour. Such a comparison of individuals that wired their brains to acquire two languages during infancy versus individuals who acquired a second language later in life, provides potential for insights into how age of acquisition influences brain function, as well as specific aspects of cognitive processing (Achard and Bullmore, 2007; Butz et al; 2014).

2.3 Sensitive Periods

The previously reported effects of age of acquisition on language skills suggests that there may be a sensitive period for second language learning. A sensitive period in language is a period in development where people are more responsive to sensory input. L1 is acquired during this sensitive period, where optimal language learning takes place (Berken et al., 2016). Age effects have been observed for perception and production of L2 vowels and consonants, with more native-like performance for earlier bilinguals (Fledge et al., 1988; Flege et al., 1999; MacKay et al., 2001). Furthermore, L2 attainment negatively correlates with age of learning, with native-like attainment being less common among late learners (Birdsong and Molis, 2001).

It has been suggested that there are cascading optimal periods for various aspects of language in development (Werker and Tees, 2005), with skill in phonology appearing to be associated with the most sensitive period that closes earliest (Simmonds et al., 2011). Exposure to the sounds of the native language begins in utero and learning-based narrowing of infant speech occurs between 6 to 12 months of age (Bosseler et al., 2013). Infants demonstrate a universal capacity from birth to perceive sounds from all languages of the world (Werker and Tees 1984; Kuhl 2010) and 8 to10-month-old infants learning a single language show language-specific boundaries in phonemic perception (Kuhl 2010). Simultaneous bilingual infants can discriminate the phonetic contrasts of each of their languages (Burns et al., 2007). In addition, early bilingual experience results in an extension of the sensitive period of language development for phonology (Flege et al., 1999). Simultaneous bilinguals are able to speak with native-like accents in both of their languages, while few later learners of a second language have this ability, indicating that simultaneous bilinguals probably set up two phonemic systems in the first year of life due to early exposure, while sequential bilinguals might bootstrap their L1's phonology, leading to an accent (Flege et al., 2006).

2.4 The Simultaneous Advantage

Given that simultaneous bilinguals learn two L1s as early as possible, and during the sensitive period, it is conceivable that this would afford them certain advantages over sequential bilinguals, who have one L1. Dual language input from birth involves a wider array of linguistic input and the learning of two phonemic systems (Werker, 2012), while neural networks are most rapidly developing (Berken et al., 2015). In contrast, late L2 learning takes place after language networks have been established, and may thus rely on modifications to existing circuitry (Berken et al., 2015). Simultaneous bilinguals have been shown to learn phonemic elements of a foreign language more easily than sequential bilinguals (Cenoz et al., 2003), and to develop a more native-like accent (Au et al., 2002). As little work has been done on transfer of linguistic skills to other domains such as music, additional work is still needed to elucidate clearer distinctions within bilingual groups based on the age at which the second language is acquired, and how this shapes language experience, cognition, and the underlying neural networks involved (Berken et al., 2016; Kousaie et al., 2017).

2.5 Early Language Learning Shapes the Brain

Neuronal maturation occurs rapidly within the first few years of life, thus this is the period thought to be most sensitive to the effects of experience, and language experience during this optimal period may result in furthering the development of neural networks (Hensch, 2005). Language experience and learning is one of the inputs described to trigger experience-related neuroplasticity (Werker and Hensch, 2015). Bilingual exposure may be utilizing developmental neuroplasticity mechanisms in order to delay the closing of the sensitive period, allowing for the development of dedicated circuitry for each language (Berken et al., 2016). Variations in early language experience have been shown to influence patterns of functional activation in language perception and production tasks (Perani et al., 1998; Mayberry et al., 2011). The neural and computational mechanisms underlying learning and sensorimotor integration reflect age of acquisition (Berken et al., 2016), with late learners showing increased levels of recruitment when processing second language syntax (Hernandez and Li, 2007). Early learning is hypothesized to lead to dedicated neural circuitry that affects cognitive and neural structures, while late learning bootstraps current networks (McNealy et al., 2007). Differences between early and late learners are also present anatomically, with late L2 acquisition being associated with thicker cortex in the left inferior frontal gyrus (IFG) and thinner cortex in the right IFG (Klein et al., 2014). Early language experience has been shown to shape ongoing neural patterns for language (Oh et al., 2010; Pierce et al., 2014). A study of Chinese-French adoptees who were monolingual French at testing displayed brain activation to Chinese linguistic tones that precisely match that of native Chinese speakers, despite the fact that participants had no subsequent exposure to Chinese after adoption and no recollection of the language (Pierce et al., 2014). These results indicate that early language experience fundamentally shapes brain anatomy and neural processing, persisting even after many years of discontinuation of language use (Oh et al., 2010; Pierce et al., 2014).

2.6 Language Processing Models and Anatomical Regions

Language processing requires different regions in separate parts of the brain to function as a network, transferring information between them in an efficient way (Friederici et al., 2013). Neural representations of speech must interface with a conceptual system, which is necessary for language perception and comprehension, and a motor-articulatory system, which is necessary for language production (Wernicke 1969; Hickok and Poeppel 2004). Similar to cortical organization of other complex functions such as vision, these two processing systems are functionally and anatomically differentiated, but interact with one another (Hickok and Poeppel 2004). One major model suggests that there is a dorsal stream for the conceptual system that projects from auditory cortices to temporal-parietal regions, and a ventral stream for the motor-articulatory system, projecting from auditory cortices to other temporal regions. (Hickok and Poeppel 2000, 2004; Saur et al., 2008; Axer et al., 2013).

Following Hickok and Poeppel's (2004) model, early cortical stages of speech perception involve auditory-responsive fields in the bilateral superior temporal gyrus (STG), which leads to the ventral and dorsal stream, which are left-lateralized. The ventral stream projects ventro-laterally to the superior temporal sulcus (STS) and ultimately the posterior inferior temporal lobe (pITL). The pITL interfaces sound-based representations of speech in the STG and conceptual representations that are cortically distributed. The dorsal stream projects dorso-posteriorly toward the parietal lobe and frontal regions. The area located within the posterior aspect of the Sylvian fissure at the boundary between the parietal and temporal lobes (sylvian-parietal-temporal) maps between auditory and motor representations of speech. Since the dorsal stream is critical for auditory-motor integration, it serves not only linguistic processes, but also non-linguistic processes such as music.

2.7 Language and Music

Language and music have similarities behaviorally and neuro-anatomically, and it is conceivable that there is transfer between these two domains (Zatorre et al., 2002; Moreno et al., 2009; Besson et al., 2011; Patel 2014). Language and music both modulate acoustic parameters to convey information, and are both generative; phonemes and tones are built by rule-based permutations into words and melodies, which are then further organized into sentences and songs (Zatorre et al., 2002). Music and language track changes in frequency spectra of the auditory signal over time (Belin and Zatorre, 2000) and, as discussed earlier, use the dorsal stream for auditory-motor integration (Hickok and Poeppel 2004). Similar to language, music also appears to be influenced by a sensitive period (Penhune 2011; Baily and Penhune, 2013; Skoe and Kraus, 2013), with age of acquisition effects being reported at both behavioural and neural levels (see Penhune, 2011 for a review). Certain anatomical and functional connectivity patterns have been shown to be predictors of musicianship (Elmer et al., 2014a), and anatomical and functional differences between early- and late-trained musicians are also seen in grey matter density and inter-hemispheric connectivity (Steele and Penhune, 2013). There are many studies that show evidence of an interaction between language and music; musical experience has been shown to facilitate the acquisition of L2 phonology (Sleve and Miyake, 2006), where musical ability accounted for variance in phonology scores, and musical abilities enhance speech in noise and prosody perception (Patel, 2014). Musical experience has been shown to modulate speech processing, and linguistic experience of learning a tonal language modulates music pitch processing (Asaridou and McQueen, 2013). Syntactic processing in both music and language has been found to rely on a shared left hemisphere network (Musso et al., 2015), and rhythmic timing for reading appears to aid children with developmental dyslexia (Thomson and Goswami, 2008). Together these results indicate a close relationship and a mutual interaction across the domains of music and language due to shared domain-general networks (Milovanov and Tervaniemi., 2011; Asaridou et al., 2015; Cason et al., 2015), which points to potential transfer of abilities.

Transfer from music to language is well studied, and the expanded OPERA hypothesis (Patel et al., 2011, 2014) offers an interesting link between these two domains. Patel's hypothesis is that musical training drives plasticity in speech-processing networks due to the following five conditions: overlap, precision, emotion, repetition, and attention. There is an anatomical overlap in the brain networks that process acoustic features used in both music and speech and, according to Patel, music places a higher demand on these networks in regard to precision of processing. Patel also states that music activities using this shared network elicit strong positive emotion, are frequently repeated, and are associated with focused attention (Patel et al., 2011). Lastly, music training places the same demands as speech on cognitive processing (Patel et al., 2014). When these conditions are met, neural plasticity drives this shared network to function with higher precision than ordinary speech, therefore speech processing also benefits (Patel et al., 2011). It is plausible that the benefit gained in speech processing by musical training is similar to the benefit of second language training in cognitive function. As discussed, when two languages are acquired simultaneously from birth, brain structure and function seem to be more effectively organized compared to sequential bilinguals (Berken et al., 2016). Perhaps the OPERA hypothesis also applies to simultaneous learning of two languages, as the dual language input might have similar traits and consequences as music training, such as a higher demand on networks and the involvement of focused attention. Additionally, since language and music share similar networks, enhanced language abilities and language processing in simultaneous bilinguals could transfer to enhanced musical abilities when compared to monolinguals or sequential bilinguals, who have less training and efficiency in these networks. Although the transfer of music to language has been the subject of many studies, few have addressed the possible transfer of language skill to music. This is one of the questions explored in the present study.

2.8 Task-based Studies: Non-native Phoneme Identification

The relationship between behaviour and the brain can be elucidated using task-based studies that pair performance on a behavioural task with brain imaging, investigating whether individual and group differences on a task are related to differences in brain anatomy and function. Of interest is the work by Golestani and colleagues (2002, 2004, 2006, 2009, 2014), who have used differences on a discrimination of a nonnative speech sound contrast to investigate the brain structure-function relationship. The Hindi dental-retroflex contrast discrimination task utilized by Golestani and colleagues investigates speech perception abilities and their previous studies relate differences in task performance to differences in brain anatomy between faster and slower learners. For instance, by using voxel-based morphometry, Golestani and collaborators (2002) showed that faster phonetic learners had more white matter volume in left parietal regions. Additionally, a functional magnetic resonance imaging study with 10 monolingual English speakers indicated that successful learning on this task resulted in recruitment of the left superior temporal gyrus, the insula-frontal operculum, and the inferior frontal gyrus (Golestani and Zatorre, 2003).

2.9 Resting-state Functional Magnetic Resonance Imaging

In contrast to the body of research in brain imaging using task-based comparisons, a newly emerging technique is resting-state functional magnetic resonance imaging (rs-fMRI), a task-independent method for understanding brain function and brain connectivity. Rs-fMRI is a measure of spontaneous low frequency (<0.1 Hz) fluctuations in the blood oxygen level-dependent (BOLD) signal while the brain is at rest (Cordes et al., 2001). Using rs-fMRI, functionally connected brain regions show correlations in spontaneous low frequency fluctuations in the BOLD signal over time (Smith et al., 2009), and correlations in fluctuations in the BOLD signal are thought to reflect brain connectivity (Lee et al., 2013). Thus, this method can investigate task-independent effects of language experience, such as age of acquisition, on brain function and connectivity (Kousaie et al., 2017). Previous work using rs-fMRI has shown that greater interhemispheric functional connectivity in the left and right inferior frontal gyri is associated with earlier age of acquisition (Berken et al., 2016). Additionally simultaneous bilinguals when compared with sequential bilinguals have stronger anti-correlation between the default mode network and the task-positive attention network that correlates with a cognitive control measure (Kousaie et al., 2017), suggesting that the more anti-correlation between these two networks, the better the performance. In addition, using rs-fMRI and spontaneous speech samples, Chai et al (2016) found that connectivity between the left anterior insula/frontal operculum (AI/FO) and the left posterior STG correlated positively with improvements in second language lexical retrieval during spontaneous speech.

Whereas task-based fMRI has been shown to be affected by motion (Oakes et al., 2005; Power et al., 2012; Power et al., 2014) and analyses using these methods have high false-positive rates (Eklund et al., 2016), rs-fMRI requires the subject to lie still during the scan, reducing motion effects. Previous task-based studies have used fMRI with tasks inside the scanner. However, testing the participant behaviorally outside the scanner, and then relating these behavioural scores to measures of brain connectivity obtained using rs-fMRI is a relatively novel way of investigating predictors of language skill and language exposure. In addition, given the anatomical and functional processing similarities between music and speech, the question of potential transfer from language to music arises, for which little work using these methods has been done to date (Asaridou et al., 2015; Hutka et al., 2015). The current study thus used resting-state fMRI, together with behavioural tasks of music and language to examine early and late learning of two languages in relation to novel language learning and the links between language and music in simulataneous and sequential bilinguals.

Chapter 3. The Present Investigation

3.1 Rationale for Study

Although previous studies have used a Hindi-dental retroflex study and Farsi sentences to explore new foreign language learning (Golestani at al., 2004; 2006), the work has not addressed the question of language transfer to novel languages by examining bilinguals who vary in the age at which they learn two languages. Additionally, while work has been done on early and late-trained musicians and the potential transfer from music to language, very few studies (Asaridou et al., 2015; Hutka et al., 2015; Moreno et al., 2015) have explored the opposite relationship; transfer from language to music. Further, work has not been done using these language and music tasks and relating behavioural performance with resting-state connectivity measurements. The present study thus sought to examine whether there is a "simultaneous advantage", as measured by a comparison of performance of simultaneous and sequential bilinguals on these language and music tasks and aimed to relate the behavioural findings to findings using resting-state fMRI.

3.2 Research Questions

A. Is there a benefit from simultaneous bilingual experience to learning new foreign language sounds, as measured on perception and production tasks?

B. Is there a benefit from simultaneous bilingual experience to performance on music perception and production tasks due to multi-modal transfer mechanisms?

C. Are there any neuro-functional patterns that differentiate simultaneous and sequential bilinguals as related to behavioural performance?

3.3 Core Hypotheses

A. Simultaneous bilinguals should outperform sequential bilinguals on foreign language tasks due to advantages in perceptual and production capabilities gained by learning two phonemic systems at the same time, as a first language, during a sensitive period for language acquisition.

B. Simultaneous bilinguals should outperform sequential bilinguals on musical perception and production tasks, due to a possible cross-domain transfer, supported by the use of similar resources in both language and music. These shared resources include auditory perception, integration of auditory and motor signals and feedback, and the neuro-anatomical overlap of regions involved in these two cognitive domains.

C. Simultaneous bilinguals should display stronger resting-state connectivity patterns than sequential bilinguals in neural networks related to language and to music tasks, such as those networks utilizing auditory-motor integration.

Chapter 4. Methods

4.1 Participants

Two groups of healthy right-handed French/English bilingual adults between the ages of 18 and 35, matched for sex and age, were compared. Participants had no musical training, were without hearing or reading impairment, and reported no history of brain injury, and no reported neurological disorders. All had high proficiency in both French and English, and had no experience in a third language. The groups were as follows: simultaneous bilinguals (N=10), who learnt both French and English from birth, and sequential bilinguals (N=11), who learnt French from birth and English after the age of 7 years. This late cut-off was chosen based on previous work (Klein et al., 2014; Berken et al., 2016; Kousaie et al., 2017) as it creates two distinct groups who potentially would present greater group differences. The cut-off was also chosen to match the early-late musician groups examined in the larger study that compared bilinguals and musicians; the usual cutoff for the late-trained musician groups is 7 years of age (Penhune, 2011; Vaquero et al., 2016b). Participants were excluded if they had any previous exposure to Hindustani-derived languages given that our foreign-language tasks use phonemes present only in these languages. To control for musical abilities and other language experience, the groups were given in-depth language and music questionnaires (Language Experience and Proficiency Questionnaire (LEAP-Q), Marian 2007; and Music Experience Questionnaire, Bailey and Penhune 2010) that screened for number of years of language experience, formal and informal musical training, and hours of practice, among other variables (See **Appendix I**). **Table 1** shows demographic information for the 21 participants. Both groups were matched on intelligence, as measured by the Matrix Reasoning subtest of the Weschler Abbreviated Scale (WAIS-IV; Weschsler, 2008), which is a non-verbal measure of global cognitive function, and on the Letter-Number Sequencing subtest of the WAIS-IV (Weschsler 2008), which assesses auditory working memory and attention. The results of these tasks are summarized in **Table 2**.

Participants were also assessed for language proficiency using multiple language tasks. First, participants completed a reading task, where they read a paragraph aloud (See **Appendix II**). This was followed by a reading comprehension condition (See **Appendix II**), where participants answered comprehension questions from the passage they read aloud. Finally, participants completed a spontaneous speech production task, in which they were presented with a picture (See **Appendix III**), and were asked to describe aloud the scene in as much detail as possible (Cookie Theft picture, Lightbulb picture, Boston Diagnostic Aphasia Exam, Kaplan and Goodglass, 1983). All tasks were completed in French and in English. Participants' proficiency was also screened in an interview in English and French before participation in the study, and through self-reported proficiency in the Language Experience and Proficiency questionnaire (LEAP-Q, Marian 2007).

Table 1. Participant demographics

	Simultaneous (N=10)	**Sequential (N=11)**	**P Value**
Sex (male/female)	4/6	4/7	—
Chronological Age (years)	24.2 (5.3)	26 (4.4)	0.402
L2 Age of Acquisition (years)	From Birth	11.2 (4.5)	<0.001
L1	French and English	French	—

Values are mean (SD).

Table 2. Intelligence Measures

	Simultaneous (N=10)	Sequential (N=11)	t Statistic	P Value
Matrix Scaled	11.2 (2.7)	9 (2.5)	1.94	0.067
Letter Number Sequencing Scaled	10.9 (2.2)	11.7 (4.1)	0.57	0.575

Values are mean (SD). Higher scores indicate better performance on tasks.

4.2 Experimental Behavioural Tasks

4.2.1 Language tasks.

4.2.1.1 Speech perception. A modified version of the Hindi Phoneme Identification task was administered (Golestani et al., 2004). Participants were presented with the Hindi dental-retroflex contrast: sounds that are phonemically different in Hindi, but perceptually very similar, especially to non-Hindi speakers, and that are not present in English or French (Golestani et al., 2004). Both the dental and the retroflex voiced, unaspirated stops were followed by the vowel /a/. The non-native perception of the retroflex sound is diminished due to perceptual reorganization early in development, (Tees and Werker, 1984), thus non-native speakers assimilate the dental-retroflex contrast and perceive both sounds as the dental consonant (Polka, 1991; Werker and Lalonde, 1988).

The sounds are synthesized so their acoustic properties can be controlled, and the stimuli are generated on a continuum: in a range from 1 to 7, in which 1 corresponds to the dental and 7 to the retroflex stop consonant. This paradigm can be best understood in the schematic below (**Figure 1**) where seven stimuli vary in equal steps in terms of the acoustic differences between adjacent items. As per Golestani et al. (2004), the parameters that were manipulated to create the continuum are the frequency transitions of the third formant (F3), as well as the center frequency of the burst.

A familiarization phase acquainted the participants with this contrast for 40 trials. After the familiarization phase, the participant completed several blocks of “learning & simultaneous testing” of 20 trials each, in which they were asked to discriminate the two sounds starting at the extremes of the continuum, when they are acoustically most different from each other. If a participant answered correctly 16 out of 20 trials of a block, they were presented with the following more difficult level, in which stimuli are each one acoustic step closer together. Since visual feedback is presented after every response, participants were able to keep track of their performance and keep learning to distinguish between the two sounds. Depending on the answers for the participant, the task could remain at the same level of difficulty until the maximum number of blocks (i.e., 10) or increase in difficulty with each block if the participant scores the required 16 out of 20. The minimum number of blocks that will be completed is 3.

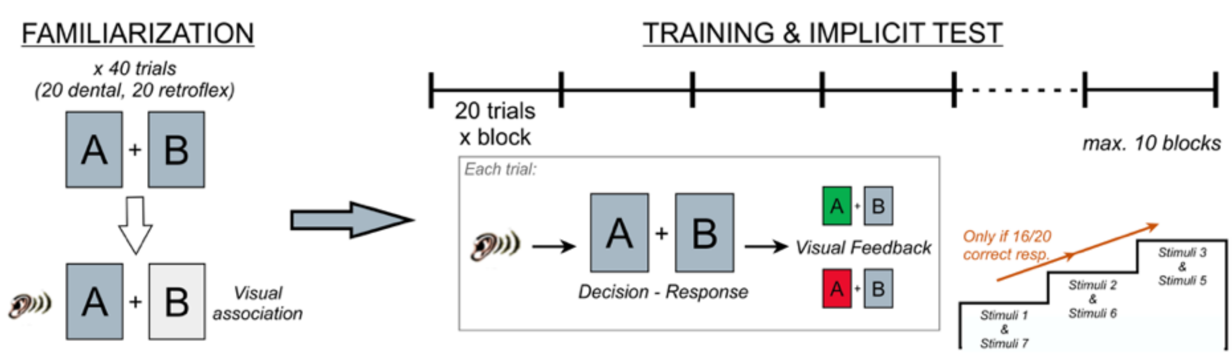


Figure 1. Hindi Phoneme Identification Task

4.2.1.2 Language Production. The Hindi Word and Sentence Imitation task presented to the participants followed the method of Reiterer (Reiterer et al., 2011). This involved repeating four Hindi words and four Hindi sentences of different lengths and phonetic complexity (7-11 syllables long) (See **Figure 2).** Hindi was selected as a foreign language for the participants, with sounds not present in either English and French. Participants were required to listen three times to the stimuli and, after the third presentation, to imitate the stimulus presented as accurately as they could. Performance on the Word and Sentence Imitation tasks was recorded and scored by three native Hindi speakers who were blind to the status of participant group. The raters have no phonetic or linguistic background and were instructed to transmit their global impression of how accurate and native the imitation sounded, when compared to the model stimuli on a scale of 1-7, with 7 being the most accurate and native-like. The speech samples were presented to the raters in a random order and a correlation coefficient for raters was computed. The Interclass Correlation Coefficient as measured by Cronback's α is 0.853, which indicates good internal consistency between the raters, hence the scores used for each participant are composite scores that are averages of all three raters.

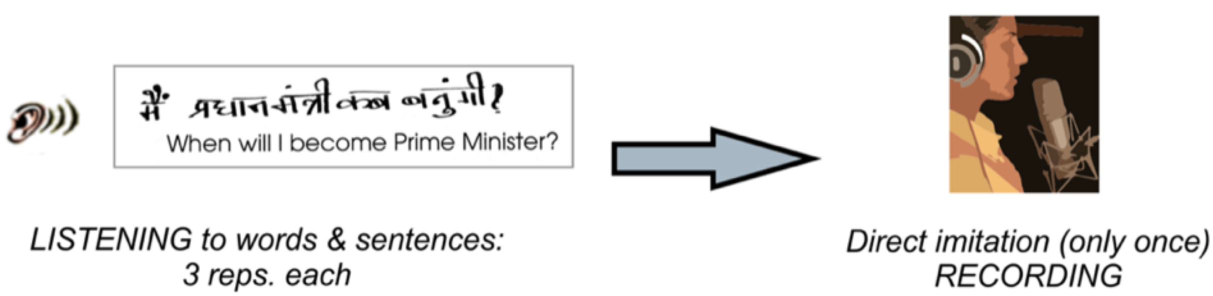


Figure 2. Hindi Word and Sentence Imitation Task

The Farsi Syllable and Word Imitation task, adopted from Golestani and Pallier (2006), required participants to listen to and imitate the Farsi voiced uvular stop /q/. As mentioned, this sound was selected as it is not present in English or French. The sound /q/ was presented in the context of 6 different consonant–vowel syllables (sound /q/ followed by -a, -o, -e, -i, -u, -A) and in the context of 6 different bisyllabic nonwords (Farsi words) (sound /q/ followed by -azA, -orme, -ese, -ise, -ulum, -Ali) (See Figure 3). As a control condition, stimuli were created with the same suffix (vowels or syllables) but starting with a native voiced velar stop: the phoneme /g/. Presentation of the native and non-native sounds followed by the same suffix was alternated. Participants were required to imitate the sound after three presentations of each of the stimuli. Performance in the Syllable and Word Imitation tasks was recorded and scored by five native Farsi speakers on a scale of 1-7 with 7 being the most accurate. Each subject was given a score based on the average accuracy rating across all of their non-native word utterances and non-native syllable utterances. The Interclass Correlation Coefficient for the raters as measured by Cronback's α is 0.799, which indicates good internal consistency thus the scores used for each participant were composite scores averaged across all five raters.

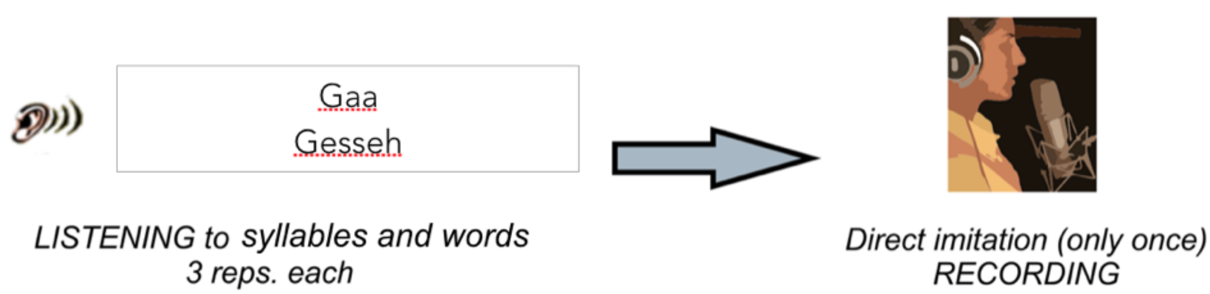


Figure 3. Farsi Syllable and Word Imitation Task

4.2.2 Music tasks.

4.2.2.1 Music perception. The Melody Discrimination task taken from Foster and Zatorre (2010) involved listening to pairs of melodies and deciding whether the second melody is the same or different from the first. This task contained three different conditions: simple melodies, transposed melodies, and a control condition of native syllable / phoneme discrimination (see **Figure 4**). Stimuli ranged from 5 to 13 notes and the melodies had a broad range of trial difficulties. Each trial consisted of the presentation of a pair of stimuli, followed by a ‘same or different’ response from the participants, indicated by a left or right mouse click. In the simple melody condition, “same” trials have both the same key and melodic contour, and contained exactly the same pitches. “Different” trials have the pitch of a single note anywhere in the melody changed by up to ±5 semitones, while maintaining the key and melodic contour. In the transposed melody condition, the second melody that is presented always had all the notes transposed 4 semitones higher in pitch compared to the first-presented melody, for both “same” and “different” trials. Thus, in this condition, “same” trials had the same contour and interval distance between each single note as the first melody, but they were transposed 4 semitones up; “different” trials had as well the second stimulus transposed higher but, in addition, they also contained one note altered by 1 semitone to a pitch outside the new pattern’s key, while maintaining the melodic contour. In order to be successful in this condition, it is necessary to use interval structure (distance between individual tones) to compare the two melodies (Dowling and Harwood, 1986)

A Syllable Sequence Discrimination task was used as a control (Foster and Zatorre, 2010). In this condition, stimuli are patterns of real speech consonant-vowel syllables, spoken in monotone. Participants listened to pairs of syllable sequences matched in length to the melodies and made a same/different judgment. The full set of phonemes consisted of 12 permutations of 8 consonants [b, k, f, n, p, r, s, j and 4 vowel sounds [o, a, u, i]. The phonemes were selected to have minimal semantic association. "Same" trials had two strings of phonemes that were exactly the same. On half the trials (the "different" trials), one syllable in the second sequence was changed. Participants completed two 30-trial blocks of each condition. Condition order was counterbalanced across participants, and trials of the 3 conditions were randomized within each block.

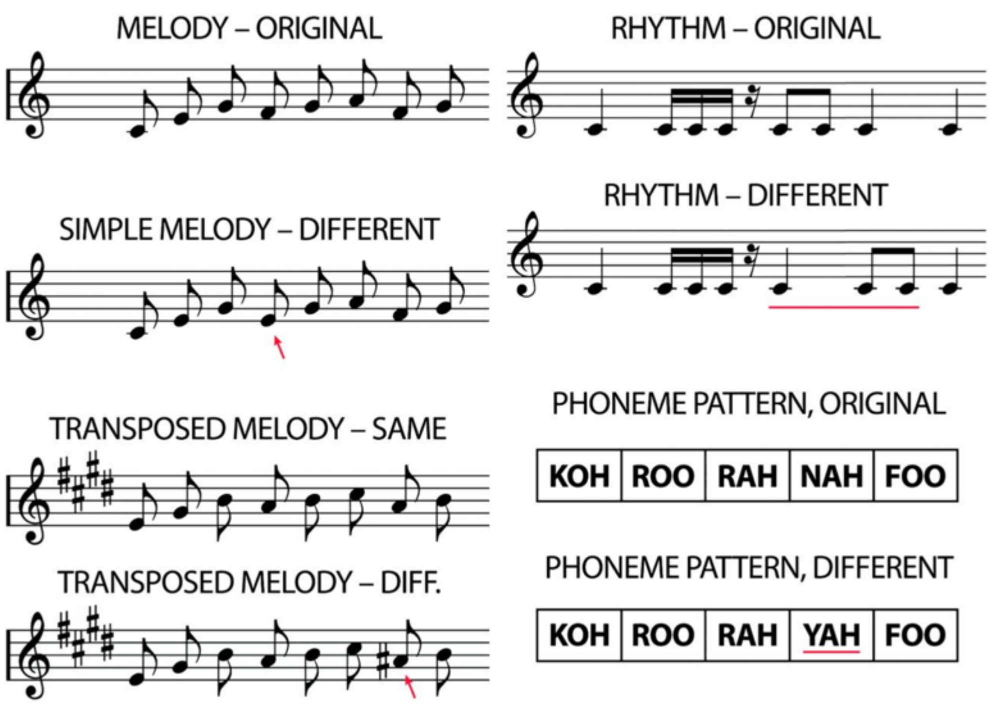


Figure 4. Melody Discrimination Task

Adapted from Foster and Zatorre, 2010, Figure 1. Cereb Cortex. 2009;20(6):1350-1359. doi:10.1093/cercor/bhp199

4.2.2.2 Music Production. A Rhythm Reproduction task taken from Chen et al. (2008) required participants to listen to rhythms and try to replicate three different auditory rhythms by tapping in synchrony on a computer mouse key with their right index finger (See **Figure 5**). Each rhythm had 11 woodblock sounds with the same total number and type of notes, differing in temporal organization. The rhythms varied in complexity. Each trial was structured in two parts: first during a "listen" condition where participants listened to the rhythm without moving, and then in the "tap in synchrony" condition, participants were instructed to tap as accurately as possible. Accuracy was measured by how close the participant is to the woodblock model sound, using a score-developed program.

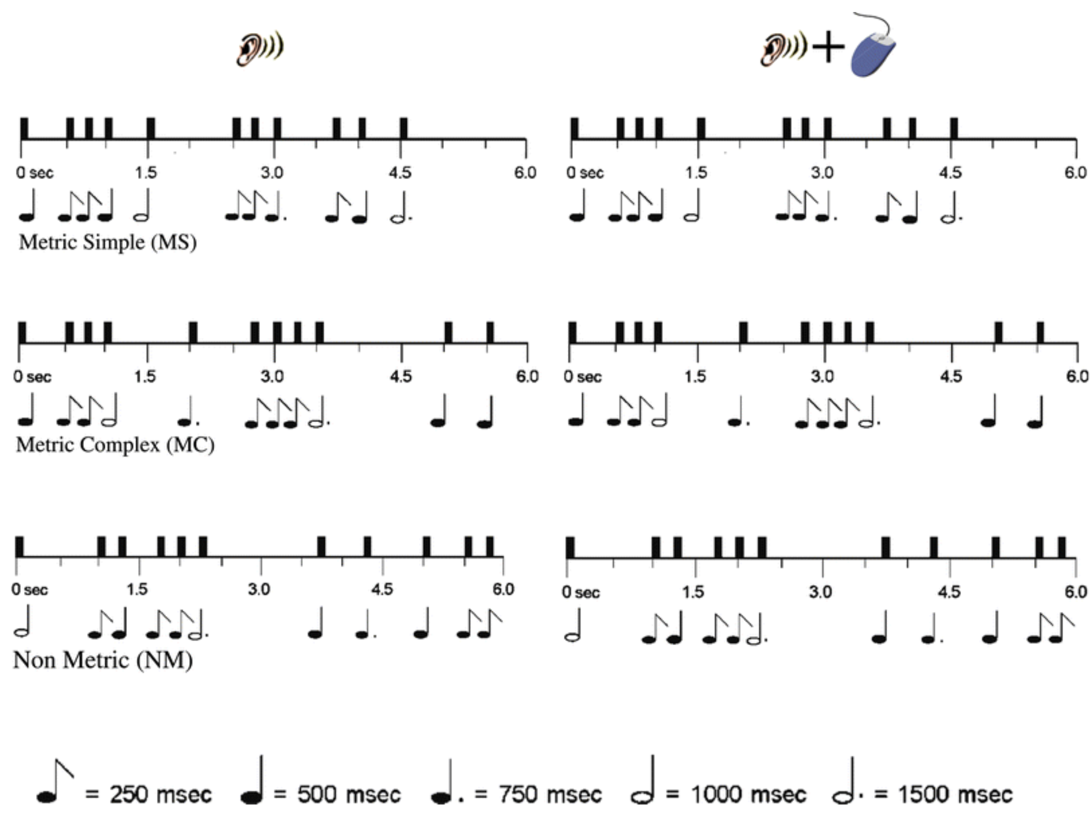


Figure 5. Rhythm Reproduction Task

Adapted from Bailey and Penhune, 2010, Figure 1. Exp Brain Res (2010) 204: 91. https://doi-org.proxy3.library.mcgill.ca/10.1007/s00221-010-2299-y

4.2.3 Specific cognitive measurements. In keeping with many studies that assess cognitive control in relation to bilingual performance (Bialystok et al., 2004; Bialystok et al., 2008; Kousaie et al., 2017), a modified version of the Simon Task (Simon and Rudell, 1967) was employed, using a computer presentation method to assess cognitive control and the stimulus-response compatibility effect, as per the method of Kousaie et al. (2017). Participants were trained to press the "Z" key for a left arrow, and the "M" key for the right arrow. In the control condition, an arrow pointing either left or right appeared in the centre of the display, and participants had to press the appropriate key to indicate the direction of the arrow as quickly as possible. This was in order to establish a response speed when no additional processing was required. For the reverse condition, the arrow was again presented in the centre of the display, and the participants were required to press the response key in the opposite direction indicated by the arrow, thus giving a measure of response inhibition. For the conflict condition, arrows were presented on either the left or right side of the display. This created congruent trials (direction and position correspond) and conflict trials (direction and position conflict). Participants had to press the response key to indicate the direction of the arrow, irrespective of the arrow's position.

4.3 Brain Imaging Methods

4.3.1 Image acquisition. All the imaging data were acquired at the McConnell Brain Imaging Centre at the Montreal Neurological Institute using a Siemens 3 Tesla Trio Scanner.

<u>Anatomical Reference:</u> Participants underwent a global 3D T1-weighted scan, with images obtained from a 3D Magnetization Prepared Rapid Gradient Echo (MPRAGE) sequence to acquire

high resolution anatomical images (matrix 256 x 256, voxel size was 1mm isometric). This scan lasted 5:03 minutes.

Resting State Functional Connectivity: Data were acquired using a T2-weighted EPI sequence to acquire images (matrix 64 x 64, 1mm isometric voxels, slice thickness 3.5mm). A total of 140 volumes was acquired. Participants were asked to lie still throughout the scanning phase, while fixating the gaze on a cross presented in the center of a screen. A head restraint was used to minimize movement. Physiological variables (heart rate, breathing) were also measured, to use as potential regressors (although this has not been used in the current analysis). This scan lasted 5:09 minutes.

4.3.2 Preprocessing. Data were preprocessed using SPM8 (Wellcome Department of Imaging Neuroscience, London, UK), using standard spatial preprocessing steps including slice-time correction, realignment, co-registration of functional to structural, normalization, and smoothing with a 5mm Gaussian kernel. Motion correction was performed using Artifact Detection Tools (ART www.nitrc.org/projects/artifact_detect/). Noise was estimated out using the anatomical CompCor method, and a temporal bandpass filter of 0.009-0.08 Hz was applied to the time series. This protocol has been used in previous research on a 3T Siemens scanner in our lab (Berken et al., 2016). The functional connectivity analyses were performed using a region of interest (ROI)-driven approach with the CONN software package (Chai et al. 2012; Whitfield-Gabrieli and Nieto-Castanon, 2012).

4.3.3 Second-level analysis. Seed-to-voxel correlations were performed using data only from behavioural tasks where significance was identified as behavioural regressors for resting state connectivity analysis. The seed-based approach was used to identify brain regions in which the BOLD signal at rest correlated positively with task score on the Hindi Phoneme Identification task. This was done by estimating the correlations between the BOLD signal in our a priori-defined ROIs (seeds) and the BOLD signal in all other voxels of the brain in relation to the Hindi Phoneme Identification score. Resting-state connectivity analysis was performed from seven seeds defined as 6 mm spheres around the coordinates of interest (Fair et al., 2009). The seed choice was based on previous reports of important cortical regions mediating auditory-motor functions in the context of second language learning or music performance /musician status. We specifically used 7 seed regions: the left temporoparietal junction (Barbeau et al., 2017), the left and right Heschl's gyrus (Patterson et al., 2002), left and right angular gyrus (Golestani et al., 2004), left putamen (Berken et al., 2015), and left inferior frontal gyrus (Golestani et al., 2004). The two participant groups were pooled for overall analysis (as per Kousaie et al., 2017), and positive correlations between the BOLD signal, task score, and each seed were computed across the entire group of participants. First-level correlation maps were produced by extracting the residual BOLD time-course from the seed region and computing Pearson's correlation coefficients between the time-course in the seed and all other voxels in the brain. The correlation coefficients were converted to normally-distributed z-scores using the Fisher's transformation, in order to allow for second-level general linear model analysis. After initial connectivity analysis, the right Heschl's Gyrus (rHG; 47.8, -15.5, 6.8) (Patterson et al., 2002) and the left temporo-parietal junction (lTPJ; -64, -48, 22) (Barbeau et al., 2017) were analyzed for group connectivity differences, as these seeds and peaks showed connectivity in the language network of interest.

Chapter 5. Results

5.1 Experimental Behavioural Results

5.1.1 Language tasks

On the Hindi-Dental Retroflex Identification task, simultaneous bilinguals differ significantly from sequential bilinguals (p= 0.024) (see **Figure 6**, **Table 3**)

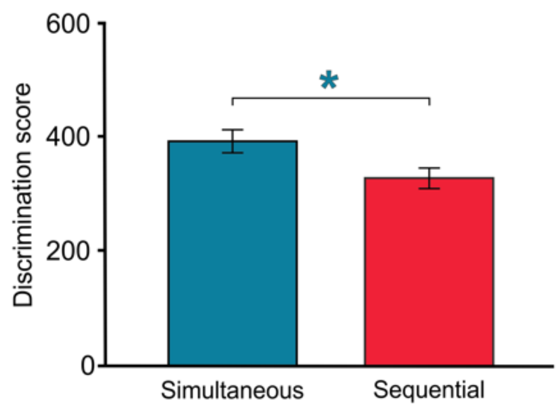


Figure 6. Group averages of performance on the Hindi-Dental Retroflex Phoneme Identification task.

Following the method of Golestani et al., (2004), raw task score is reported on the y axis, the maximum is 600. The groups are significantly different, p= 0.024

The groups did not differ on the Hindi Word and Hindi Sentence Imitation tasks, nor on the Farsi Syllable and Farsi Word Imitation Tasks (see **Figure 7**, **Table 3**).

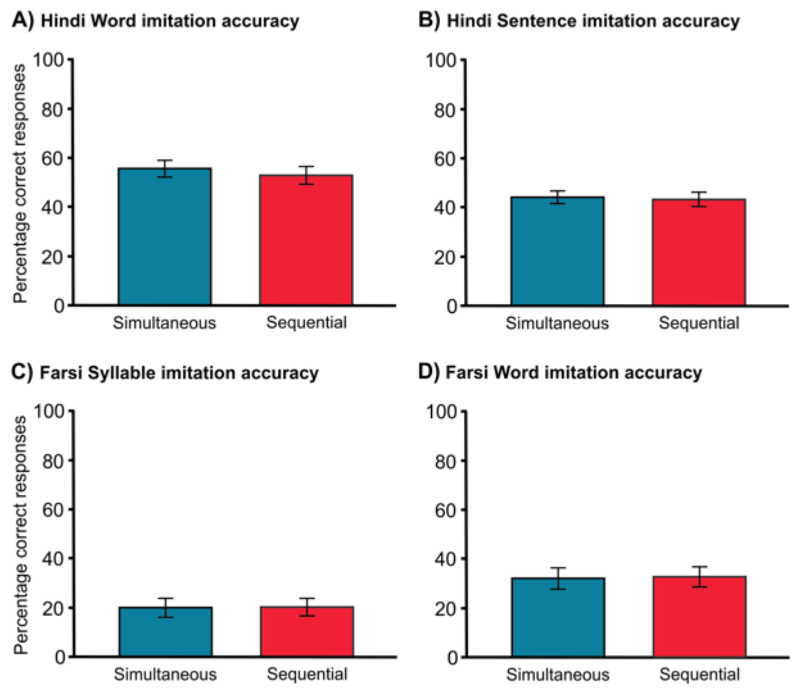


Figure 7. Group averages of Foreign-language Imitation tasks

Hindi Word (A) Hindi Sentence (B) Farsi Syllable (C) and Farsi Word (D) Imitation tasks. Accuracy is measured on the y axis in terms of percent correct, thus the maximum is 100.

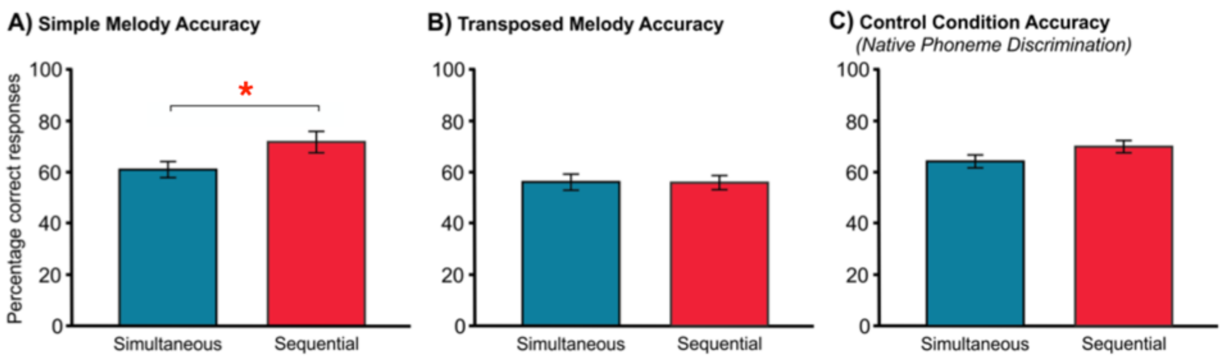
Table 3. Language Tasks

	Simultaneous (N=10)	**Sequential (N=11)**	**t Statistic**	**P Value**
Hindi Phoneme Identification	393.3 (62.7)* 66%	328.7 (58)* 55%	2.45	0.02
Hindi Word Reproduction	67.9 (8.2)	68.8 (10.5)	0.55	0.90
Hindi Sentence Reproduction	36.1 (9.5)	37.1 (7.1)	0.24	0.82
Farsi Syllable Reproduction	20.0 (11.9)	20.2 (11.6)	0.05	0.96
Farsi Word Reproduction	32.3 (13.6)	33.0 (13.5)	0.12	0.90

Values are mean (SD). Higher scores indicate better performance on the different tasks, asterisks show significant group differences. For the Hindi Phoneme Identification task, the maximum score is 600. For all other tasks, the maximum score is 100.

5.1.2 Music tasks

For the simple melody discrimination condition, sequential bilinguals outperform simultaneous bilinguals (p=0.05). No other significant differences were observed between the groups on the remaining music perception or production tasks. (**see Figure 8, Figure 9, Table 4**).



Simple Melody (A) Transposed melody (B) and Native Phoneme Discrimination (C) conditions. Accuracy is measured on the y axis in terms of percent correct, thus the maximum is 100. For Simple Melody, the groups are significantly different (p=0.05).

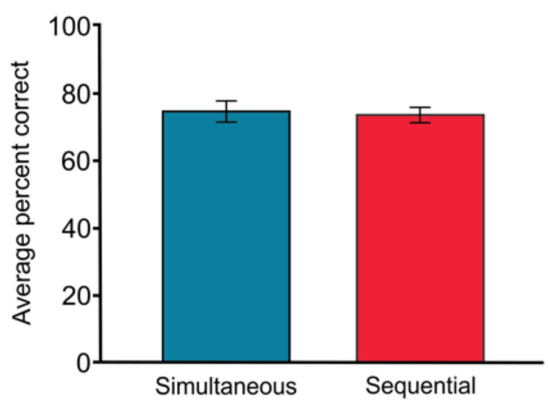


Figure 9. Group averages of the Rhythm Reproduction task

Accuracy is measured on the y axis in terms of percent correct, thus the maximum is 100.

Table 4. Music Tasks

	Simultaneous (N=10)	Sequential (N=11)	t Statistic	P Value
Melody Simple	61.0 (9.9)*	71.8 (13.7)*	2.06	0.05
Melody Transposed	56.2 (9.7)	55.9 (8.9)	0.06	0.95
Melody Phoneme	64.2 (7.7)	69.8 (7.9)	1.67	0.11
Rhythm % correct average	75 (10)	73 (7)	0.27	0.78

Values are mean (SD). Higher scores indicate better performance on tasks, asterisks show significant group differences. The maximum score for all tasks is 100.

5.1.3 Specific Cognitive Tasks. There were no significant differences between the groups on Simon interference, interference suppression, or response inhibition (see **Table 5**).

Table 5. Cognitive Measurements – Simon Task

	Simultaneous (N=10)	Sequential (N=11)	t Statistic	P Value
Simon Interference	14.4 (16)	14.9 (17.4)	0.07	0.95
Interference Suppression	94.2 (45.7)	93.5 (40.6)	0.03	0.97
Response Inhibition	62 (31.8)	59.9 (29.5)	0.16	0.88

Values are mean (SD). Higher scores indicate better performance on tasks.

5.2 Brain Imaging Results

Whole brain connectivity analysis from the seven seed regions that were sampled and their associated peaks are summarized below in **Table 6**. Using the score on the Hindi-dental retroflex tasks, the left temporoparietal area positively correlated with the right planum temporale. The seed in right Heschl's gyrus significantly correlated with the left supramarginal gyrus, see **Figure 10** and **Figure 11 and Table 6**.

Table 6. Seed to Voxel Connectivity relation to Hindi Discrimination Score

Seed Region and Coordinates (x y z)	Peak Region and Coordinates (x y z)	k (voxels in cluster)	t Statistic	Cluster p-FDR
L Temporoparietal Junction [1] (-64 -48 22)	R Planum Temporale (46 -38 14)	385	5.08	0.0046
R Heschl's Gyrus [2] (47.8 -15.5 6.8)	L Supramarginal Gyrus (-62 -28 42)	116	5.83	0.0430

Seed coordinates from the following sources:
1 (Barbeau et al., 2017); 2 (Patterson et al., 2002)

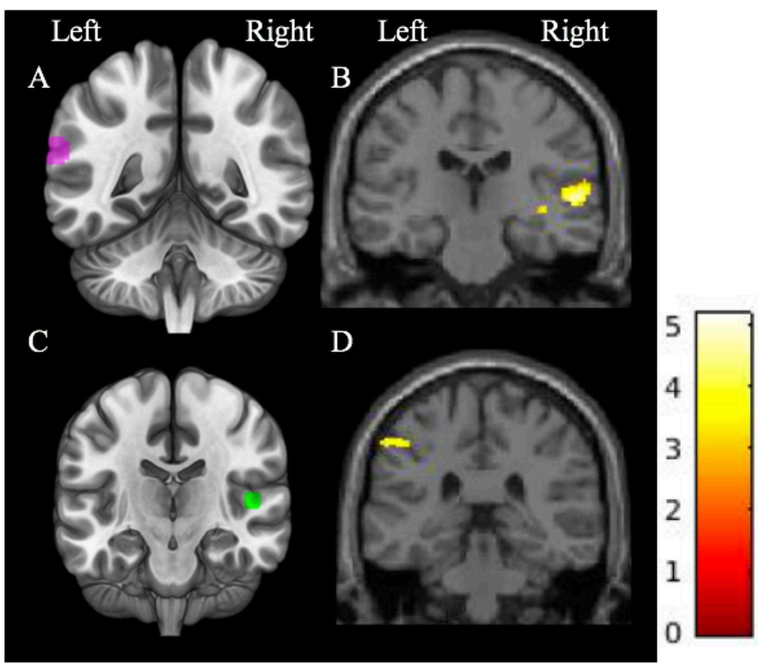


Figure 10. Seeds and Associated Peak Regions.

Seeds are shown in pink (LTPJ) and green (RHG) and peak functional connectivity is shown in yellow, according to the scale. Coronal view of the L TPJ seed (A) found to be significantly connected to the R PT Peak (B); Coronal view of the R HG seed (C) found to be connected to the L SMG peak (D).

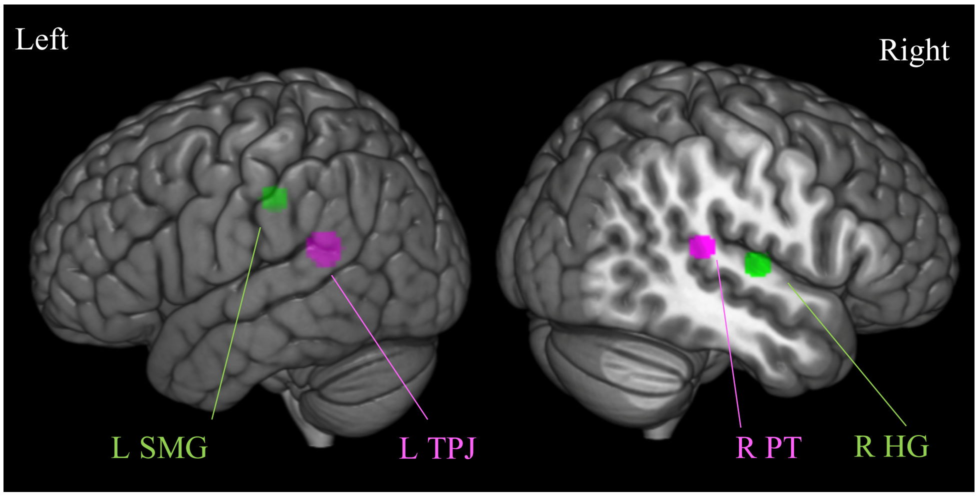


Figure 11. Seeds and Peaks are non-overlapping regions within the language network.

Seeds are the L TPJ and the R HG. The LTPJ showed significant connectivity with the R PT (pink), and the R HG presented significant connectivity with the L SMG (green), both in relation to the performance on the Hindi discrimination task

Greater connectivity between the L TPJ and the R PT is associated with better performance on the Hindi Dental Retroflex Phoneme Identification task ($p<0.005$, R square= 0.52). Connectivity between groups is significantly different, simultaneous bilinguals have significantly higher connectivity between L TPJ and R PT than sequential bilinguals ($p = 0.05$). See **Figure 12**.

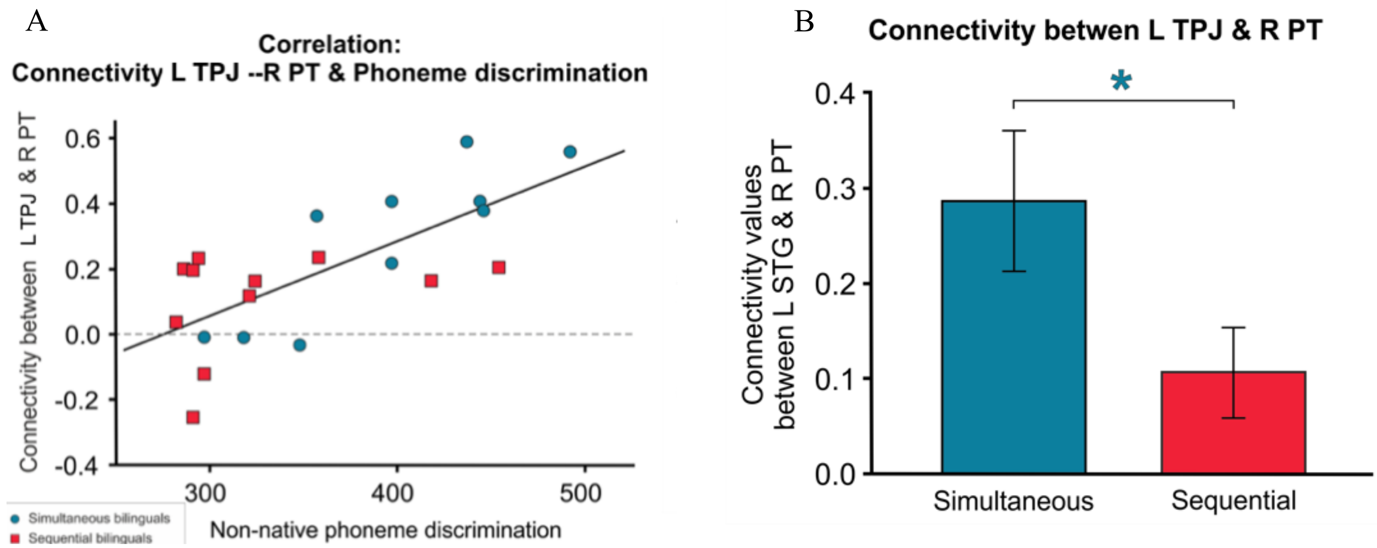


Figure 12. Connectivity between L TPJ and R PT.

Scatterplot (A) shows the distribution of simultaneous and sequential bilinguals across the correlation with the Hindi-discrimination score ($p<0.005$, R Square = 0.52). Bar graph (B) shows the significant difference in the connectivity between R HG and L SMG in the simultaneous vs. the sequential bilinguals ($p=0.05$). The two participant groups were pooled and positive correlations between the BOLD signal, Hindi Phoneme Identification task score, and each seed was computed, across the entire group of participants. After initial connectivity analysis, the L TPJ was analyzed for group connectivity differences.

Greater connectivity between the R HG and the L SMG is associated with better performance on the Hindi Dental Retroflex Phoneme Identification task ($p<0.001$, R square= 0.62). Connectivity between groups is significantly different, simultaneous bilinguals have significantly higher connectivity between R HG and L SMG than sequential bilinguals ($p < 0.05$). See **Figure 13.**

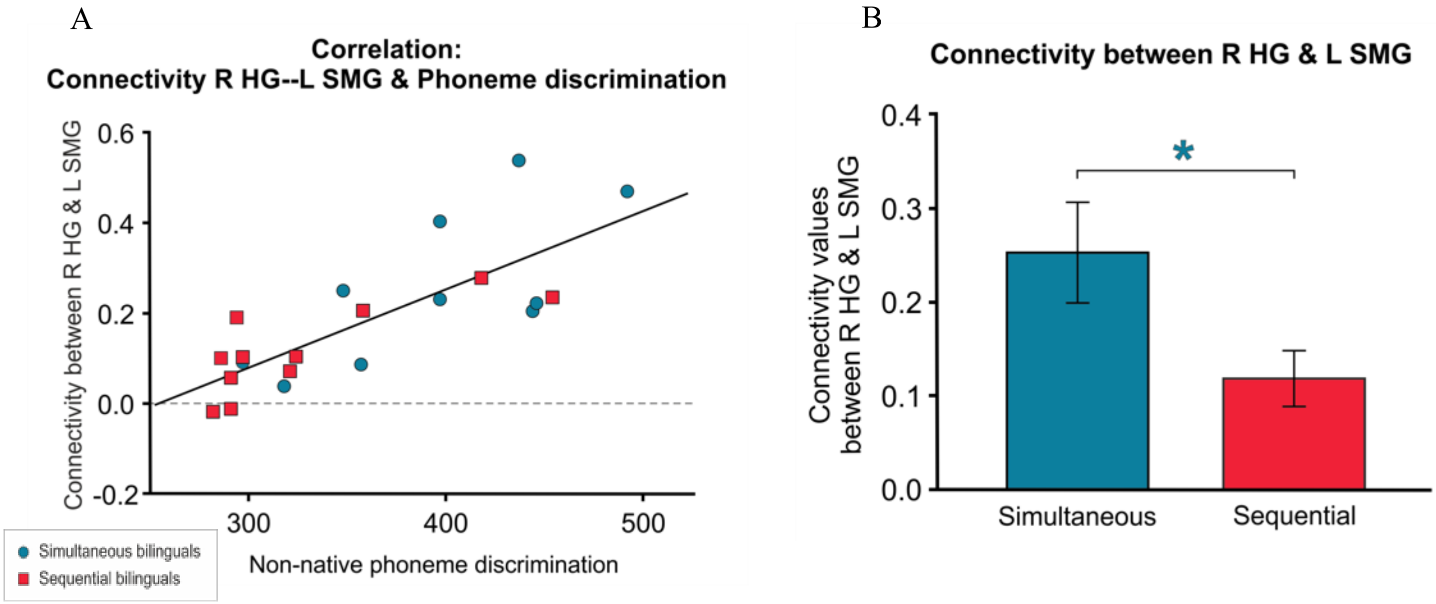


Figure 13. Connectivity between R HG and L SMG.

Scatterplot (A) shows the distribution of simultaneous and sequential bilinguals across the correlation with the Hindi-discrimination score ($p < 0.001$, R square = 0.62). Bar graph (B) shows the significant difference in the connectivity between R HG and L SMG in the simultaneous vs. the sequential-late bilinguals ($p < 0.05$). The two participant groups were pooled and positive correlations between the BOLD signal, Hindi Phoneme Identification task score, and each seed was computed, across the entire group of participants. After initial connectivity analysis, the R HG was analyzed for group connectivity differences.

Chapter 6. Discussion

We examined the effect on behaviour and on brain networks of simultaneous as compared to sequential bilingual language experience. Our specific focus was on whether simultaneous bilinguals would show (i) an advantage in perceiving and producing subtle phonemic contrasts in novel languages, as well as (ii) a cross-domain transfer to comparable music perception and production tasks. Simultaneous bilinguals perform significantly better than sequential bilinguals at identifying the Hindi dental-retroflex contrast. In addition, performance on this foreign-language perception task was linked to resting-state connectivity differences between the groups. At least on the basis of this task, simultaneous bilingual experience appears to result in advantages in perception of new language contrasts as compared to those with sequential bilingual language exposure.

Phonology is an early acquired language feature, being subject to highly sensitive periods which close earliest (Werker and Tees, 1984; Simmonds et al., 2011). Exposure to two languages simultaneously during this sensitive period results in the setting up of two phonemic systems in the first year of life (Flege et al., 2006). Simultaneous bilinguals thus develop a broader phonemic bank, potentially allowing them to develop the ability to perceive new foreign language sounds more easily as compared to sequential bilinguals, and thus explaining better performance on the Hindi Phoneme Identification task, which involves foreign-language perception. While this idea is not new, we show that on this task the effect is related to having exposure to the two languages from the time of birth as it is present in simultaneous bilinguals, and not in bilinguals who learn a second language later in life. We extend this finding by linking the behavioural result to resting-state connectivity analysis, showing potential brain connectivity profiles related to this skill acquisition.

Regarding the imaging results, performance on the Hindi Phoneme Identification task was related to stronger interhemispheric connectivity for simultaneous bilinguals compared to sequential bilinguals within specific brain regions thought to be important for sensory-motor integration. Specifically, among the regions of interest (ROIs) used in the current study, we chose the left temporoparietal junction (LTPJ) because it encompasses one of the crucial nodes of the dual-route model for language processing described by Hickok and Poeppel (2004): the Sylvian-parietal-temporal region. This region is part of the dorsal stream of the language network and is thought to be important for mapping between auditory and motor representations of speech (Hickok and Poeppel, 2004). It contains Wernicke's area and the angular gyrus, both of which are involved in language comprehension and processing (Binder et al., 1997). Previous studies using positron emission tomography (PET) show that the L TPJ is consistently affected in patients with many types of aphasia (Metter et al., 1990).

In our study, simultaneous bilinguals had significantly greater connectivity compared to sequential bilinguals between the L TPJ and the right planum temporale (R PT) correlated with better performance on the Hindi Phoneme Idenfitication task. The temporal lobe bilaterally is involved with processing auditory signals for speech and non-speech material, but the left PT is an asymmetric brain region involved in speech processing, while the right PT is usually involved more predominantly in processing musical tones (Dorsaint-Pierre et al., 2006). However, it has been proposed that new foreign language sounds are at least initially processed in the right hemisphere (Qi, 2015; Callan, 2014) as non-linguistic sounds. The stronger interhemispheric connectivity between this right auditory-processing area (i.e., R planum temporale) and the left hemisphere region responsible for auditory-motor integration (i.e., the L TPJ) in simultaneous bilinguals suggests that the degree of interhemispheric functional connectivity is shaped by age of language acquisition. Furthermore, the quality of interhemispheric connectivity seems to affect an individual's ability to discriminate new foreign language sounds.

Given the importance of interhemispheric connectivity in the temporal lobes for sound processing, a right hemisphere temporal-lobe seed was also chosen. To continue investigating interhemispheric connectivity in sensory-motor integration areas in relation to the significantly different performance across groups on the Hindi Phoneme Identification task, we chose the right Heschl's gyrus (R HG) as a seed. This right hemisphere region in primary auditory cortex is specialized for spectral resolution of acoustic cues, is involved in tonal processing (Penhune et al., 2011), and is thought to be involved when new foreign language sounds are potentially initially processed as non-linguistic sounds (Qi 2015). Interestingly, we found that greater connectivity between the R HG and the left supramarginal gyrus (L SMG) resulted in better performance on the language perception task, and once again, simultaneous bilinguals had significantly greater connectivity compared to sequential bilinguals between these two regions. Previous reports have observed activation in the L SMG during fMRI tasks while participants are making phonological decisions (Hartwigsen et al., 2010) and when a change in the initial stop consonant of syllables is perceived (Celsis et al., 1999). In addition, the left SMG has been previously described as engaged in detecting changes in phonological units, and is thought to be involved in verbal working memory processes (Deschamps et al., 2013).

The stronger interhemispheric connectivity found in the simultaneous bilinguals likely indicates a more efficient language network, possibly allowing for more detailed phoneme perception and thus better performance of this Phoneme Identification challenge. Increased interhemispheric connectivity could increase processing time from sound to meaning and allow faster processing of sounds and faster learning of phonemic information. Greater interhemispheric resting-state functional connectivity as a result of early language experience has previously been observed in our laboratory between homologous regions of the inferior frontal gyri in simultaneous bilinguals (Berken et al., 2016). Conceivably, one manifestation of early language experience is greater overall interhemispheric connectivity in the language network and sensory-motor integration areas, allowing for the observed behavioural benefits in new foreign language perception.

These language perceptual advantages were not found to translate to better scores in the new foreign-language production tasks used in the current experiment. This may be due to the difficulty of the tasks and the short exposure to the auditory material. However, with increased training and practice, it is conceivable that the perceptual advantage observed in simultaneous bilinguals would lead to a better production of the new foreign language sounds. Further, speaking a language also requires understanding of other speakers, and this perceptual advantage of the simultaneous bilinguals will result in better detection and comprehension of subtle differences in non-native phonemes, and ultimately may yield better understanding of the new foreign language.

The current protocol did not contain a longitudinal training component for re-testing understanding of foreign languages, since we were more interested in baseline abilities due to participants' linguistic experience. This, however, would be an avenue for future research.

Despite previous reports showing cross-domain transfer effects from music-training experience to linguistic abilities (Schellenberg et al., 2004; Moreno et al., 2011; Gerry et al., 2012) and from bilingual experience to other cognitive functions (Bialystok et al., 2011), no significant difference was found between the bilingual groups on music production, nor did we observe any cognitive control differences between our groups. This suggests that any advantages of simultaneous language experience appear to be confined to the language domain. This study suggests that there may not be cross-domain transfer as a result of simultaneous bilingualism, although further studies are needed to investigate more fully transfer of abilities from bilingual experience to music skills and vice versa.

Lastly, a difference was found between the groups on the simple melody task, with the sequential bilinguals performing significantly better than the simultaneous bilinguals. As the groups do not differ in terms of musical training, this difference may be explained by effects on perceptual abilities related to age of acquisition. While early exposure enhances perception and connectivity in the language processing network, later exposure and bilingual achievement may result in a more flexible network that can be used to process musical stimuli without training. Given that late language acquisition requires a person to utilize their first language's phonemic network to understand and produce the sounds of another language (Flege et al., 2006), it is conceivable that those who achieve high proficiency in a language through late acquisition have trained a more domain-general auditory network which leads to an increased ability to perceive subtle differences in simple melodies. Since this difference did not translate to the transposed melody condition, or the music production task, more studies with a larger number of participants are needed to investigate these effects in relation to early as compared to late language training.

Chapter 7. Conclusion

7.1 Conclusions

One important criterion related to language learning and brain organization is the age at which people learn languages, which may occur during an optimal period for brain organization. Simultaneous and sequential bilinguals, who are differentiated by their age of language acquisition, provide an interesting model to look at sensitive periods for language perception, production, and transfer to other domains. As a result of early exposure to two languages within the first year of life, simultaneous bilinguals show perceptual advantages in their language abilities, likely due to the learning of two phonemic systems within a sensitive period. This might allow them to better distinguish phonemes of new foreign languages that are not present in their own language, as shown in the present study with the Hindi-dental/retroflex contrast. We found the ability to distinguish between these two foreign sounds to be significantly correlated with increased interhemispheric connectivity in simultaneous bilinguals when compared with sequential bilinguals. Specifically, this relationship was found for the connectivity between the L Temporoparietal junction and the R Planum Temporale, and the R Heschl's gyrus and the L Supramarginal gyrus. The increased connectivity in these language network regions adds to the understanding that these two groups of bilinguals are neuro-functionally different from one another. When two languages are acquired simultaneously from birth, brain structure and function in the language network seem to be more efficiently organized compared to sequential bilinguals, by allowing greater interhemispheric connectivity.

7.2 Limitations and Future Directions

One of the main limitations of the current study is the small sample size, as tasks were only completed by 10 and 11 participants in each group. Additionally, the study did not have any training phase, but tested only baseline ability, thus it is possible that foreign-language production, and music perception and production differences were not found due to the longer training and exposure time they may need to manifest these effects. Additionally, a group whose age of acquisition of a second language falls between the simultaneous and late sequential bilingual groups could be recruited (i.e those with an age of acquisition between 2-6 years of age) to investigate a wider range of age of acquisition and its impact on phonetic learning. Recruiting more participants with a larger range of age of acquisition, could shed light on whether the perceptual advantage and increased connectivity found in the present study are a result of simultaneous learning specifically, or at what age there might be a cut off to confer similar benefits.

In addition, future studies should try to combine different neuroimaging techniques (i.e., structural and functional MRI, MEG, or EEG with structural MRI), and correlations of task performance with fMRI during the task and at rest as these comparisons may also lead to more concrete conclusions. Lastly, this experiment is part of a larger study that is still in progress, and future plans are being made to test monolingual participants on these same foreign-language and music perception and production tasks, which may help the team to better interpret the current results.

Appendix I

Language Experience and Proficiency Questionnaire (LEAP-Q)

Health and Language History Questionnaire

DATE: ______________________ **Participant ID:** ____________________

<u>Section 1:</u> Demographic information

3. Date of Birth (day/month/year): 2. Age:
4. Sex:
5. Handedness:
   (Please also complete attached handedness inventory)
6. Education: What is the highest level of education that you have completed? You can include information such as "attended but did not complete"
   - Primary school
   - High School; where did you completed high school (province, Country)?
   - CEGEP
   - College/University undergraduate degree (e.g., BA, BSc)
   - Graduate degree (e.g., Master's degree)
   - Graduate degree (e.g., Ph.D., MD)
   - Other; please specify)
7. What is your current marital status?
   - Single – never married
   - Married / Common-law
   - Separated
   - Divorced
   - Widowed
   - Cohabit
8. What is your main occupation?
9. If you are married, what is your spouse's highest level of education and their main occupation?

10. What is your mother's highest level of education and her main occupation (if retired, what was her occupation prior to retirement?)

11. What is your father's highest level of education and his main occupation (if retired, what was his occupation prior to retirement?)

12. Where were you born?
    If not in Canada, how long have you been in Canada?

1

13. Where were your parents born? (If not in Canada, please indicate if they are currently in Canada, how many years they have been in Canada, their native language and other languages that they speak):

	Country of birth	Years in Canada	Native language	Other languages
Mother				
Father				

13. Do you play a musical instrument?
    If "yes",
    a. Do you have any formal musical training?
    b. Do you still play?
    c. How frequently?
    d. Can you read music?
    e. Do you consider yourself a musician?

<u>Section 2:</u> Language background and experience

1. Do you speak more than one language?
   If you answered "no", skip to the next section
   If you answered "yes", please list the languages that you speak in order of fluency (with the most fluent first):

2. Please rate your current ability on reading, writing, speaking, and listening for all languages you know according to the following scale (fill in the number in the table):

1	2	3	4	5	6	7
Very poor	*Poor*	*Fair*	*Functional*	*Good*	*Very good*	*Native-like*

Language	Reading	Writing	Speaking	Listening

2

3. Have you ever taken a standardized language proficiency test in your non-native language(s) (e.g., TOEFL? If yes, please indicate the name of the test, the languages assessed, and the scores that you received. If you can't remember, please guess. If you remember only the percentile of your score, write it in the place of the score.)

Test	Language	Actual Score	Guessed Score

4. Do you have a foreign accent in the languages that you speak? Please rate how strong you think your accent is according to the following scale (fill in the number in the table):

1	2	3	4	5	6	7
None	*Little*	*Some*	*Intermediate*	*Strong*	*Very Strong*	*Extremely Strong*

Language	Strength of accent

5. At what age did you first start to learn each language in terms of speaking (at what age did you speak your first words?), reading, and writing, and the number of years you have spent learning each language.

Language	Age first learned the language			Number of years spent learning (cumulative)
	Speaking	Reading	Writing	

6. Please indicate the age at which you started to learn each language in the following situations – indicate the age in the boxes for only situations that are relevant.

Language	At home	At school	After immigrating to the country where spoken	Informal setting (e.g., nannies or friends)	Software (e.g., Rosetta Stone)	Other (please specify: ________)

3

7. Please indicate the language(s) used by your teachers for general instruction (e.g., history, math, science) at each schooling level. If you switched language within a level please indicate the level and the languages.

   Primary School:

   High School:

   CEGEP:

   College/University:

   Other:

8. Have you ever lived or travelled in another country for more than three months where you were required to speak another language other than your native language(s)? If so, please indicate the country, your length of stay and the year that you visited, the language(s) that you learned or tried to learn, and your frequency of use of the language while visiting the country and currently. Please use the following scale and fill in the number in the table:

1	2	3	4	5	6	7
Never	*Rarely*	*Occasionally*	*Sometimes*	*Frequently*	*Very Frequently*	*Always*

Country	Length (cumulative) and Year of stay	Language	Frequency of use during visit	Frequency of use currently

9. How good do you think you are at learning new languages (e.g., relative to friends or people you know). Circle one:

1	2	3	4	5	6	7
Very poor	*Poor*	*Fair*	*Neutral*	*Good*	*Very good*	*Excellent*

10. At what age do you consider that you became fluent in each language in terms of speaking, reading and writing? Please indicate an age in each box; if you do not consider yourself fluent please indicate "not fluent".

Language	Age of Fluency		
	Speaking	Reading	Writing

4

11. Please estimate the total number of hours each day that you spend engaged in the following activities, and indicate what percentage of that time you spend engaged in that activity in each of the languages that you know (please write down the languages). If you are not currently engaged in an activity using that language write "0"; the total percentage for each activity should equal 100%.

Activity	Total hours per day	Language: ____________	Language: ____________	Language: ____________
Listen to radio / watching TV				
Reading for fun				
Reading for work				
Reading on the internet				
Writing emails to friends				
Writing articles / papers				
Other (specify):				

12. Please estimate the percent of conversations that take place in each of your languages, and what percentage of that is with the following people. The total across languages should equal 100% and the total within each language should equal 100%.

Language	% of total conversations	Family members	Friends	Classmates	Co-workers	

13. How often do you use your languages for the following activities? Use the following scale and fill in the number in the table.

1	2	3	4	5	6	7
Never	*Rarely*	*Occasionally*	*Sometimes*	*Frequently*	*Very Frequently*	*Always*

Language	Arithmetic (e.g., count, add,	Remember numbers (e.g., student	Dream	Think	Talk to yourself	Express anger or affection

5

	multiply)	ID, telephone)				

14. What proportion of your current friends are speakers of the languages that you know well? Please indicate the language and the percentage of your total number of friends that speak that language (the total should equal 100%).

Language	Percent of total number of friends

15. In which language (among your two best languages) do you feel you usually do better or feel more comfortable? Indicate the language for each condition.

	At home	At work / At school	At a party or other social context
Speaking			
Writing			
Reading			

16. Do you mix words or sentences from two languages in your own speech (e.g., say a sentence in one language but use a word or phrase from another in the middle of the sentence)? Yes / No

If you answered "no", please move on to the next section.

If you answered "yes", please continue with the following questions

17. a) List the two or more languages that you mix with different people, and estimate the frequency of mixing/switching in normal conversation according to the following scale (fill in the number in the table):

1	2	3	4	5	6	7
Never	*Rarely*	*Occasionally*	*Sometimes*	*Frequently*	*Very Frequently*	*Always*

Languages mixed/switched	Relationship	Frequency
	Family members	

6

	Friends	
	Classmates	
	Co-workers	

17. b) Under what situations from those listed below are you most likely to mix/switch between two languages, and which languages do you mix/switch between? Please list all language combinations that apply to each situation (e.g., English and French; from English to French).

Situation	Mix/Switch between which languages (list all that apply)
When I don't know the word in one language	
A word comes to me faster in one language	
It is difficult for me to control which language I am speaking in	
I switch between languages on purpose	
Other (specify):	

17. c) Please indicate if there are situations in which you are more likely to mix or switch between languages and what those situations are.

17. d) Please indicate if there are situations in which you think that it is inappropriate to mix or switch between languages, and what those situations are.

18. Do you feel that you are bilcultural or multicultural (e.g., growing with parents or relatives from different cultures, or you lived in different cultures for extended periods of time)? Yes / No

If "yes", which culture (and its language) do you identify more strongly with? Use the following examples and scale to indicate the strength of your cultural identification:

1	2	3	4	5	6	7
None	*Very Weak*	*Weak*	*Intermediate*	*Strong*	*Very Strong*	*Extremely Strong*

7

Culture and its Language	Like its food	Like its music	Like its art	Like its cities and landmarks	Will root for its athletic teams

19. Is there anything else that you think is interesting or important about your language background or language use?

<u>Section 3:</u> Health information

1. Do you have any visual problems (e.g., cataract, colour blindness, wear glasses)?
2. Do you have any hearing problems (e.g., hearing loss, do you wear a hearing aid)?
3. Have you ever had a head injury?
   If "yes",
   What was the cause?
   What was the outcome?
4. Do you have a history of neurological disorder?
5. Have you ever had any major surgery? What for?
6. Do you have any metal prostheses, screws, plates or fragments?
7. Do you have any piercings or tattoos? How many, and where are they located?
8. Do you have any allergies?
9. Are you claustrophobic?
10. Are you pregnant?
11. Have you ever had an MRI before? For what?
12. Do you currently take any medications?
    If "yes", please list the medications and indicate what condition you are taking

8

them for and how long you have been taking them for

Medication	Reason for consumption	Duration of consumption

13. Do you drink alcohol?
    If "yes", approximately how many drink of alcohol do you have per week?

14. Do you use non-prescription drugs for recreational purposes? If "yes", which ones and how many times per week?

Drug	Frequency of use (per week)

9

Identification:

Name:

Email:

Telephone:

Handedness Inventory
(Modified from Annett, 1967. Source: Briggs and Nebes, 1975)

Name ______________________________ Sex____________ Age______________

Indicate hand preference	Always left (-2)	Usually left (-1)	No preference (0)	Usually right (1)	Always right (2)
1. To write a letter legibly					
2. To throw a ball to hit a target					
3. To play a game requiring the use of a racquet					
4. At the top of a broom to sweep dust from the floor					
5. At the top of a shovel to move sand					
5. To hold a match when striking it					
7. To hold scissors to cut paper					
8. To hold thread to guide through the eye of a needle					
9. To deal playing cards					
10. To hammer a nail into wood					
11. To hold a toothbrush while cleaning teeth					
12. To unscrew the lid of a jar					
column total:					
Total Score: (range -24 to +24)					
Designation:	_____ **Right-handed** (+9 and above) _____ **Mixed-handed** (-8 to +8) _____ **Left-handed** (-9 and below)				

Are either of your parents left-handed? If yes, which? __________________________________

How many siblings of each sex do you have? Male _______________ Female _______________

How many of each sex are left-handed? Male _______________ Female ______________

Which eye do you use when using only one (e.g. telescope, keyhole)? ____________________

Have you ever suffered any severe head trauma? ______________________________________

Music Experience Questionnaire (MEQ)

1

Experimenters - Please mark participant responses in the coloured cells below each question.
When possible please convert verbal responses to the corresponding numerical response, otherwise write out the participant response verbatim.

Name

Participant ID Number

Testing Date (dd/mm/yyyy)

Date of Birth (dd/mm/yyyy)

Gender (1 = Male, 2 = Female)

Do you consider yourself to be a musician? (1 = Yes, 2 = No)

Can you read music? (1 = Yes, 2 = No) For example: Can you read and play a basic piece of music (e.g. a single-lined melody)?

Can you write music? (1 = Yes, 2 = No) For example: Can you write a single line of melody by dictation?

Rank the source of your motivation when you first began music: (1=Completely Internal - 5=Completely External) e.g.: was it YOUR idea or your PARENTS?

Rank the level of your current motivation for music: (1=Very Low - 5=Very High)

Are you currently receiving formal music training? (1 = Yes, 2 = No)

Private lessons? (1 = Yes, 2 = No)

Group lessons? (1 = Yes, 2 = No)

Degree? (1 = Yes, 2 = No)

If yes, what is your current GPA? *Please specify out of 4.3 or 4.0*

What type of degree will you receive or have you received in music, if any? (1 = None, 2 = Collegial, 3 = Bachelor's, 4 = Master's, 5 = PhD)

Describe your theory training in terms of rhythm, pitch, melody structure, etc.

Approximately how many hours per day are spent listening to music?

Rank the type of listening typically involved (1 = Very Passive - 5 = Very Active)

Describe your sound engineering/sound mixing/sound training, if any:

Voice Experience
Group
Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Hours/Week of lessons (past):

Last formal level passed (if any):
level
program

2

Solo
Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Hours/Week of lessons (past):

Last formal level passed (if any): Specify program and level
level
program

Dance Experience
Group
Style (1 = Ballet, 2 = Jazz, 3 = Tap, 4 = Hip Hop, 5 = Break Dancing):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Hours/Week of lessons (past):

Last formal level passed (if any):
indicate level here
write out program name here

Solo
Style (1 = Ballet, 2 = Jazz, 3 = Tap, 4 = Hip Hop, 5 = Break Dancing):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Hours/Week of lessons (past):

Last formal level passed (if any): Specify program and level
indicate level here
write out program name here

3

Instrumental

******REMINDER: include any elementary and high school programs (i.e. recorder, band, etc), include time played in school if following a music program******

Instrument 1 (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Lesson Type (1 = Private, 2 = Group)

Hours/Week of lessons (past):

Last formal level passed (if any):

Instrument 2 (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation):

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Lesson Type (1 = Private, 2 = Group)

Hours/Week of lessons (past):

Last formal level passed (if any):

indicate level here
write out program name here

Instrument 3 (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation):

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Lesson Type (1 = Private, 2 = Group)

Hours/Week of lessons (past):

Last formal level passed (if any):

indicate level here
write out program name here

4

Instrument 4 (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation):

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock):

Age of Start:

Age of Stop:

Hours/Week (current):

Yrs of Lessons:

Lesson Type (1 = Private, 2 = Group)

Hours/Week of lessons (past):

Last formal level passed (if any):
indicate level here
write out program name here

Sibling Musical History
Sibling 1:
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start (*the earliest musical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

Sibling 2:
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start *(the earliest musical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

5

Sibling 3:
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start *(the earliest musical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

Sibling 4:
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start *(the earliest musical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

Parent's Musical History
Father
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start (*the earliest msuical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

Mother
Dance (1 = Yes, 2 = No)

Sing (1 = Yes, 2 =No)

Instrument (1 = Piano, 2 = Guitar, 3 = Violin, 4 = Drums, 5 = Flute, 6 = Saxophone, 7 = Bass, 8 = Cello, 9 = Clarinet, 10 = Electronic Manipulation)

Style (1 = Classical, 2 = Jazz, 3 = Pop, 4 = Rock)

Age of start (*the earliest msuical experience among dance, singing or instrumental)*

Age of stop

Instruction (1 = Yes, 2 = No)

Lesson Type (1 = Private, 2 = Group)

6

Did your home environment play a role in your mativation to play music? (1 = Yes, 2 = No)

What level of education have your parents obtained?
Mother (1 = No HS, 2 = HS, 3 = College, 4 = Bachelor's, 5 = Master's, 6 = PhD)

Father (1 = No HS, 2 = HS, 3 = College, 4 = Bachelor's, 5 = Master's, 6 = PhD)

Appendix II

English Story and Comprehension Questions

English

Lindsay decided she needed a cabinet for her new dishes. She measures the empty space in her kitchen before leaving for the lumberyard. After looking at the cedar and oak boards, she concluded that she much preferred pine. She went to the hardware store after buying her wood. She purchased brass handles and hinges, as well as a big hammer. The price was thirty-two dollars. She rushed to her workshop in the basement as soon as she got home. Lindsay wanted to finish her corner cabinet before the Christmas holidays.

Questions:

1. What was the name of the person in this story?
2. What did she decide she needed?
3. What did she do before going out?
4. Where did she go first?
5. What types of wood did she look at?
6. Which did she like best?
7. Where else did she go?
8. What did she buy while she was there?
9. Where did she go after leaving that place?
10. Is the person an adult or a child?
11. Is the person a man or a woman?
12. Where was she going to put the cabinet?
13. Where did she buy the wood?
14. What kind of hinges was she going to put on the cabinet?
15. Where was she going to build her cabinet?
16. When (at what time of year – what season) did Lindsay build her cabinet?

French Story and Comprehension Questions

Français

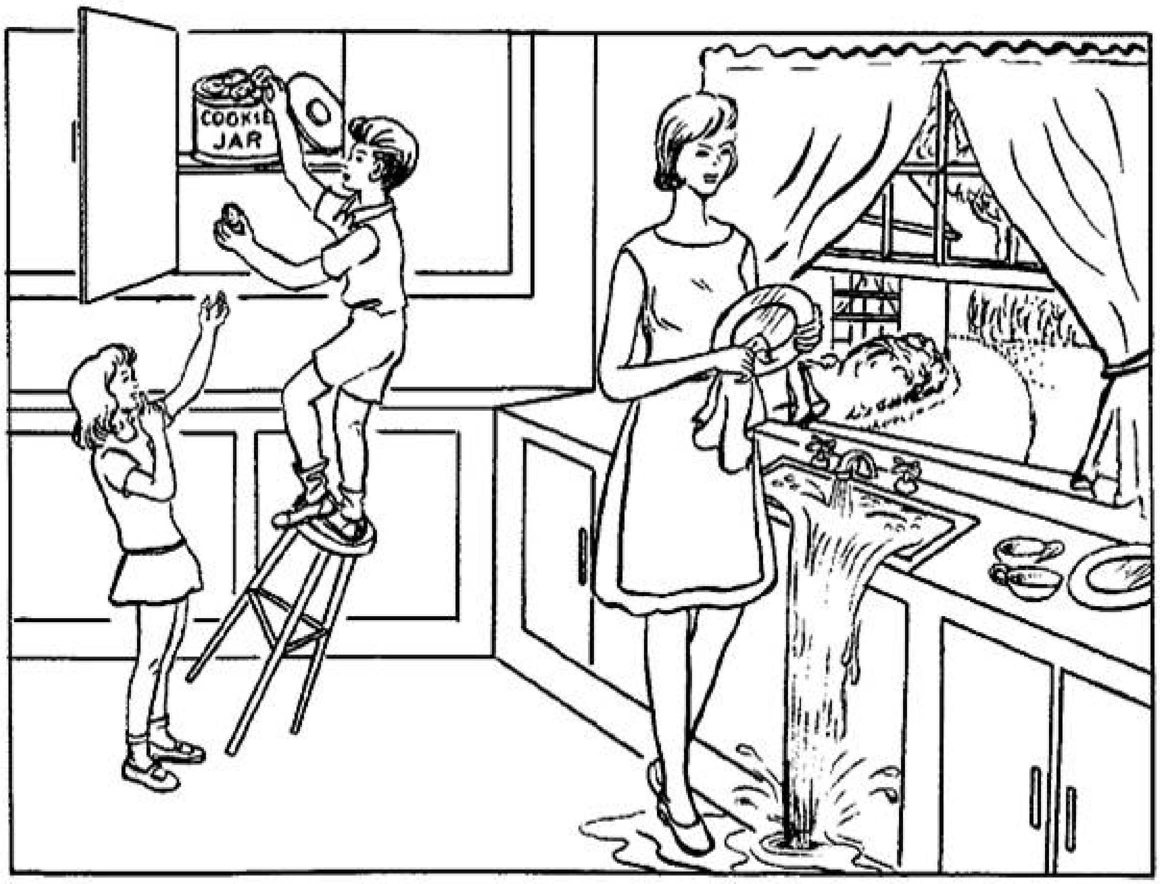
La chambre d'invités de Michelle paraissait défraichie. Elle a décidé de redécorer avant la visite de sa sœur, prévue pour Pâques. Avant de conduire jusqu'au centre d'achats, elle a trouvé un échantillon de son papier-peint et l'a emporté avec elle. Après avoir contemplé les peintures orange et écarlate, Michelle prit vert pomme pour un mur et beige pour le plafond. Elle a aussi choisi un pinceau, un petit rouleau et de la térébenthine, qui ont coûté vingt-quatre dollars en tout. Elle s'est arrêtée chez un fleuriste sur son chemin et a commandé une grande plante pour être livrée le jour même.

Questions :

1. Quel était le nom de la personne de cette histoire?
2. Que voulait faire cette personne?
3. Quand voulait-elle avoir fini?
4. Qu'a-t-elle fait avant de sortir?
5. Où est-elle allée?
6. Quelles couleurs a-t-elle regardées?
7. Quelles couleurs a-t-elle achetées?
8. Qu'a-t-elle acheté d'autre?
9. Où est-elle allée en dernier?
10. Qu'est-ce qu'elle a acheté là-bas?
11. Est-ce que la personne dans cette histoire est adulte ou enfant?
12. Est-ce que cette personne est un homme ou une femme?
13. Où sa sœur allait-elle rester?
14. Comment s'est-elle rendue au centre d'achats?
15. Est-ce que cette personne a acheté sa peinture avant ou après avoir pris son papier-peint?
16. Est-ce qu'elle a arrosé la plante en rentrant chez elle?
17. A quel moment de l'année (quelle saison) a-t-elle redécoré la pièce?

Appendix III

Cookie Theft Picture (Describe in English)



Lightbulb Picture (Describe in French)

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