Age-related sensitive periods influence visual language discrimination in adults

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INTRODUCTION

From the first days of life, language perception involves both auditory and visual speech information. The visual information available in talking faces contains linguistic cues often correlated with and complementary to the acoustic signal (e.g., Munhall and Vatikiotis-Bateson, 1998; Yehia et al., 1998). In adults, seeing talking faces enhances speech perception (Sumby and Pollack, 1954), and in some cases, can perceptually dominate heard speech (see McGurk and MacDonald, 1976; Campbell, 2009). Similarly, there is evidence suggesting that very young infants can match heard speech with the corresponding talking faces (Kuhl and Meltzoff, 1982; Patterson and Werker, 2002), detect a mismatch between heard and seen speech (Kushnerenko et al., 2008; Bristow et al., 2009), and integrate mismatching audiovisual speech (Rosenblum et al., 1997; Burnham and Dodd, 2004; Desjardins and Werker, 2004). Moreover, both adults and young infants are able to discriminate between languages just from silent talking faces (Soto-Faraco et al., 2007; Weikum et al., 2007; Ronquest et al., 2010).

Sensitive periods in language development have been documented for both auditory and visual speech perception. Infants begin life with broad perceptual sensitivities that support learning phonetic properties from many of the world’s languages (e.g., Saffran et al., 2006), but as their experience accumulates across the first year of life, their perceptual sensitivities become attuned to match the language(s) present in their environment (see Werker and Tees, 2005, for a review). This pattern is seen in age-related changes between 6 and 10 months of age for the discrimination of minimal pairs that are phonologically relevant to the infant’s native language (e.g., Werker and Tees, 1984; Werker and Lalonde, 1988; Best et al., 1995; Bosch and Sebastián-Gallés, 2003; Tsao et al., 2006; Albarede-Castellot et al., 2011), in visual language discrimination (Weikum et al., 2007; Sebastián-Gallés et al., 2012), and even in auditory-visual matching (Pons et al., 2009). This tendency, often referred to as “perceptual narrowing” (Scott et al., 2007), seems to be extensively constrained by maturational factors, particularly in the domain of phonetic consonant discrimination (Peña et al., 2012).

An interesting case is when the listener is regularly exposed to more than one language (as is arguably the case for most of the world’s population; see Brutt-Griﬃler and Varghese, 2004). Infants exposed to two different languages seem to maintain their sensitivity to the distinctions used in each of their languages. For example, at the end of the ﬁrst year of life, bilingual infants can discriminate the heard speech sounds (Bosch and Sebastián-Gallés, 2003; Burns et al., 2003; Albareda-Castellot et al., 2011) and visual speech (Weikum et al., 2007) of both of their native languages. Thus, early life exposure to two languages results in a perceptual system that reﬂects, and is responsive to, the input from each language.

In stark contrast to the ﬂexibility that “crib” bilinguals show, individuals who acquire a second language in adulthood have notorious difficulty learning to discriminate some of the phonological categories in their second language (L2). One of the best...
known examples is the difficulty Japanese learners often have in discriminating the English /t/ vs. /l/ contrast (Goto, 1971). It is equally hard for English speakers to learn to discriminate the dental /da/ vs. retroflex /Da/ sounds used in Hindi (Werker et al., 1981). In both cases, while intensive training can lead to some improvement, performance does not reach the level of native speakers (Tees and Werker, 1984; Lively et al., 1993; McClelland et al., 2002). Even highly proficient bilinguals, such as Spanish-native speakers of Catalan, can learn to discriminate contrasts specific to their L2 (i.e., /e/ vs. /ɛ/; Sebastián-Gallés and Soto-Faraco, 1999) but they nonetheless show slower improvement than native speakers of the contrast. The age at which performance deteriorates can vary with the non-dominant language when speech is presented acoustically (Navarra et al., 2003) and visual information (Weikum et al., 2007; Sebastián-Gallés et al., 2012). Nonetheless, there is some latent sensitivity to visual information even among adults, but only if they know one of the languages. For example, Soto-Faraco et al. (2007) found that adult Spanish, Catalan, and Spanish-Catalan bilinguals were able to discriminate visual Spanish from visual Catalan significantly better than chance, whereas Italian and English speakers were not. Using two languages that were less similar, English and Spanish, Ronquest et al. (2010) reported similar results.

A question that these studies do not address is whether there is an influence of AoA on the test languages on visual language processing, in the same way that this variable plays an important role in auditory language perception. There is one suggestion in the literature of such an effect in a study of visual language discrimination of Finnish vs. Swedish where a trend was observed for better discrimination by participants’ age of arrival in Sweden (Öhrström et al., 2009). The current study investigated precisely this question: Does age of acquisition of an L2 play a role in the ability to visually discriminate the L2 language from other languages? In order to investigate this issue, we tested adult participants from varied (non-French) language backgrounds who had acquired English at different ages (from birth to late childhood) on the visual French and English stimuli (used in previous work with infants, Weikum et al., 2007; Sebastián-Gallés et al., 2012). English and French differ both rhythmically and phonetically. Rhythmically, the two languages differ as English is a stress-timed language and French is a syllable-timed language (Pike, 1945;
Abercrombie, 1967). Phonetically, segmental differences, such as more vowel lip-rounding and greater degree of lip protrusion in French, and the use of interdental articulations in English, exist between the two languages (Benoit and Le Goff, 1998).

On the basis of the literature reviewed above, showing age of acquisition effects on phonetic (segmental) and supra-segmental auditory speech perception, we hypothesized that visual language discrimination would also be influenced by the age at which the second language was learned. We therefore tested adults who had learned English at different ages. We divided the adults into three groups. The first group (Infant Exposure) was comprised of adults who had acquired English in infancy (by 2 years)—either as a single language or in a dual language-learning environment. Because an effect has been found for visual language discrimination between 6- and 8-months (Weikum et al., 2007), we were interested to determine whether this decline in visual language discrimination provides evidence for an optimal period in infancy that has life long consequences, or whether it shows a (re)organization process that has begun, but has not yet become permanent. However, adults are not accurate in reporting precisely when input from a second language began (especially if it was early in life), so we decided to use a broad range (0–2) to cover infancy. Thus, although a cut-off at 6 months of age would have provided an ideal comparison for the perceptual change found in the infant work, to be conservative we used a 2 year cut-off. The second group (Early Exposure) was comprised of adults who had acquired English after age 2 and before 6 years. Previous studies examining auditory speech perception and production have suggested that age 6 may be an important cut-off for phonological processing and accent-free speech (e.g., Flege and Fletcher, 1992; Flege et al., 1995) and studies have also shown that even early bilinguals may show differences on difficult phonological tasks (Pallier et al., 1997; Sebastián-Gallés and Soto-Faraco, 1999). Thus, this middle age group was comprised of Early, but not “crib” bilinguals. From a theoretical perspective, this group would include individuals who acquired the second language once the perceptual reorganization for the first language had already been established. The third group (Late Exposure) was comprised of adults who had acquired English after age 6 and before age 15. We compared these three groups on their ability to discriminate English visual speech from French visual speech (a non-native language for all the participants).

We predicted that the adults’ ability to discriminate English from French based on visual information alone would depend on the age at which they learned English. To control for the possibility that short-term familiarity with a speaker could enhance language discrimination, we showed all participants videos of three different bilingual speakers and tested participants under two conditions. In the random condition, paired sentences from all three speakers were presented in random order. In the blocked condition the participants viewed all the sentence pairs from each of the three speakers in succession. If the blocked condition (where participants were able to see the same speaker over and over) conferred any short-term familiarity benefits, we would expect improved performance among the speakers in the blocked condition.

**METHODS**

**PARTICIPANTS**

In accordance with the Behavioral Research Ethics Board at the University of British Columbia, all participants gave informed consent before participating. There were 120 adult participants (see Table 1 for details). Sixty participants had learned English as a first language (L1) before age 2. In this group, 40 participants had learned only English and 20 participants had learned English in conjunction with another language (Infancy multilinguals). An additional group of 60 had learned English as a second language (L2) after the age of 2 years. These L2 participants were further divided according to the age at which they started to learn English. Thirty participants had learned English as a second language in early childhood (age 2–6 years; Early multilinguals), and 30 participants had learned English learned as a second language in late childhood (age 6–15 years; Late multilinguals). Although the first language (L1) of the L2 participants was quite varied, the majority of the languages were either Cantonese or Mandarin (see Table 2 for participant language background information). None of the participants were fluent in French.

All subjects were highly proficient in English. All courses at the university they were attending were in English, and all who had English as a second language had passed the mandatory TOEFL requirement. In addition, we asked participants who had learned English as a second language, or simultaneously with another language from birth to rate themselves on their English proficiency. The first 11 participants rated their proficiency on a 7-point Likert scale where (1) represented native-like and (7) represented beginner. We switched to a more detailed questionnaire (Desrochers, 2003) for the remaining participants. This included 8 oral comprehension and 14 oral production questions. For each question, participants rated the difficulty of various speech activities on a 9-point Likert scale as very easy (1) to very difficult (9). The mean answer to these 22 questions was used as each participant’s proficiency score. Proficiency in English was not available for 2 participants who had learned English simultaneously with another language.

**Table 1 | Participant Data.**

|                  | N  | Age English learned | Male/ Female | Mean age in years at test (SD)* |
|------------------|----|--------------------|--------------|---------------------------------|
| L1               |    |                    |              |                                 |
| English only     | 40 | 0–2                | 21M/19F      | 25.3 (7.1)                      |
| Infant multilinguals | 20 | 0–2                | 9M/11F       | 21.1 (3.1)                      |
| L2               |    |                    |              |                                 |
| Early multilinguals | 30 | 2–6                | 11M/19F      | 20.5 (2.1)                      |
| Late multilinguals | 30 | 6–15               | 13M/17F      | 21.2 (4.2)                      |

*Age at test was only available for 109 participants.

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1One of the subjects in the Late multilingual group whose first language was Mandarin subsequently became proficient in both French and English, but no longer uses French.
STIMULI
The faces of three balanced bilingual (French/English) speakers were recorded while they recited sentences in both English and French. The French and English sentences were taken from the French and English versions of the book “The Little Prince,” and were selected to overlap in content (same sentence translations) and to be roughly equivalent in length (see Appendix for examples). The sentences from each language were then individually digitized with the sound removed, to create 8–13 s silent video clips. There were no significant differences between sentence lengths for the English [average 37.24 (SD = 6.00) syllables] and the French [average 33.24 (SD = 5.88) syllables] video clips.

PROCEDURE
Participants were tested in a sound-attenuated room and sat at eye level with the monitor (17”) of a Pentium 4 PC. From a distance of ~75 cm, the participants watched 24 pairs of sentences, and each pair was played consecutively. For each pair of sentences, a white fixation point would first appear in the center of the black screen for 500 ms. Following this, a red frame with the speaker silently reciting one of the sentences would appear and was followed by a 1 s interval of black screen before the second sentence in the pair was played inside a green frame. Participants were asked to press the right mouse button (marked with an S) if they thought both clips were in the same language, and the left mouse button (marked with a D) if they thought that they were from different languages. During the second sentence (green frame) participants had been instructed to respond as soon as they were sure of their judgment. If a response was not made during the second sentence, a white question mark appeared and was followed by a 1 s interval of black screen before the participant moved on to the next speaker. This allowed for a test of potential improvement across exposure to each speaker. The order of the speakers was counterbalanced for each condition and the speaker order for the blocks was counterbalanced across participants.

RESULTS
Using group mean averages, a series of one-sample t-tests revealed that across all ages of acquisition, both the English L1 (English learned alone in infancy or simultaneously with another language) [M = 60%, t(59) = 6.84, p < 0.001] and English L2 (Early and Late multilinguals) [M = 54%, t(59) = 3.00, p < 0.05] discriminated the languages significantly better than chance, and did so in both the Random [M = 57%, t(59) = 4.56, p < 0.001] and Blocked [M = 58%, t(59) = 4.99, p < 0.001] speaker blocks. A univariate analysis of variance (ANOVA) including sex, language background (English as L1 or English as L2), and speaker order (blocked or random) yielded only a significant main effect for language background [F(1, 119) = 8.08, p < 0.05; Figure 1]. Simple main effect analyses showed that the English L2 speakers performed significantly worse than the English L1 speakers [F(1, 119) = 5.40, p < 0.05].
To probe whether age of acquisition of English had an effect on visual speech discrimination, we ran additional analyses. An ANOVA analyzing the effect of age of English acquisition (age 0–2, 2–6, 6–15) yielded a significant effect \( F_{2, 117} = 5.55, p < 0.05 \). Planned comparisons focusing on the multilingual participant groups revealed that the Infant and Early multilingual age groups did not perform significantly different from each other \( F_{1, 48} = 0.24, p = 0.63 \), but did perform better than adults who acquired English in late childhood (6–15 years) \( F_{1, 78} = 3.90, p = 0.05 \). In fact, performance was significantly better than chance for multilingual learners who acquired English in infancy \( M = 56\% \), \( t_{19} = 2.69, p < 0.02 \) and learners who acquired English in early childhood \( M = 57\% \), \( t_{29} = 3.53, p < 0.02 \), but not for participants who acquired English in late childhood \( M = 52\% \), \( t_{29} = 0.82, p = 0.417 \). These results are graphically illustrated in Figure 2, which reveals as well that the vast majority of subjects in the infancy and early childhood groups, but not in the late English acquisition group, performed better than chance.

We performed several follow-up analyses with the multilingual groups in order to explore whether proficiency or number of years of experience, rather than age of acquisition (see Flege et al., 1997), could account for our findings. There was no significant correlation between discrimination performance and self-rated proficiency in English \( r_{177} = -0.18, p = 0.12 \). Correlating discrimination performance with total years of experience with English \( r_{170} = 0.09, p = 0.48 \), and exposure to French \( r_{179} = 0.02, p = 0.84 \) also failed to reach significance. However, there were significant group differences between the means for proficiency scores, 1.16 (Infant multilinguals), 1.48 (Early multilinguals), and 1.95 (Late multilinguals), \( F_{2, 74} = 5.92, p < 0.01 \) as well as the group means for years of experience, 20.1 (Infant multilinguals), 16.5 (Early multilinguals), and 12.4 (Late multilinguals), \( F_{2, 65} = 40.14, p < 0.01 \).

To further probe the possibility that self-rated proficiency or years of experience with English may have contributed to our findings, we equated the Early and Late Multilingual groups by selecting subsets with equivalent proficiency scores or years of experience. We selected a subset of Late multilinguals who scored between 1 and 3 on the proficiency scale [with a mean score = 1.48(0.67) that was equivalent to the Early multilinguals = 1.53(0.60)]. The results from the full sample concerning the influence of AoA were replicated in the restricted Late multilingual sample as the late learning multilinguals again failed to perform significantly better than chance \( M = 53.3\% \), \( t_{22} = 1.47, p = 0.16 \).

Similarly, we also tested the effect of AoA by selecting a subset of English L2 speakers who had an equivalent amount of experience in total number of years (12–19 years), and then within this group, compared the effects of early and late AoA. This resulted in 2 groups: 20 early bilinguals with a mean = 15.3(1.26) years of experience and 16 late bilinguals with a mean = 14.06(2.17) years of experience, wherein the mean years of exposure were not significantly different. The results from the full sample concerning the influence of AoA were replicated in this restricted sample: early bilinguals performed significantly better than chance \( M = 56.0\% \), \( t_{19} = 2.79, p < 0.05 \) while the late learning bilinguals did not \( M = 52.6\% \), \( t_{15} = 0.96, p = 0.35 \).

**DISCUSSION**

The age at which a language is learned (in this case, English) during childhood influences the ability to visually discriminate this language from others in adulthood. Interestingly, this effect of AoA could be examined separately from the influence of years of exposure or proficiency (self-rated). When tested on a visual language discrimination task, most participants who had learned English as a second language in late childhood (after 6 years) failed to discriminate English from French, whereas most participants who had learned English earlier, as infants (0–2 years old) or in early childhood (2–6 years old), succeeded. Allowing the participants to view the speakers in a blocked vs. random speaker order did not seem to have an influence on discrimination performance.

According to prior research, infants who are familiar with both languages (French and English since early infancy) retain the capacity to continue discriminating the languages visually at 8 months, while their monolingual counterparts fail (Weikum et al., 2007). This benefit arising from bilingual exposure appears to confer an advantage in adulthood too, as adults familiar with both test languages perform visual language discrimination significantly better than those familiar with only one of the test languages (Soto-Faraco et al., 2007). Based on the infant research, one might argue that the successful discrimination of French and English by monolingual English infants at 4 and 6 months,
followed by a decline at 8 months, predicts that monolingual English adults should also fail to discriminate English and French (Weikum et al., 2007). However, the present findings (see also Soto-Faraco et al., 2007 for converging results) show that monolingual participants do indeed successfully discriminate their native language from an unfamiliar language. One reason adults succeed and older infants do not, may be that adults are able to use a wider and more sophisticated range of strategies to resolve the task. However, if it was only strategy on the part of the monolingual adults that leads to their success in language discrimination, then the failure of our English L2 late learning adults to tell apart French from English is surprising. Instead, our results suggest that exposure to one of the languages any time before age 6 allows for continued discrimination in adulthood.

Sensitive periods have been previously identified for phonemic segment discrimination in auditory spoken languages (for a review see Werker and Tees, 2005) and for acquisition of syntax in signed languages (Newport, 1990). The results from this study further support these findings by showing that sensitive periods also exist for language discrimination based on visual speech cues alone. Although it was not the intention of this study to address what these cues may be (see Soto-Faraco et al., 2007; Ronquest et al., 2010; Navarra et al., submitted), for work investigating the role of visual phonetic and rhythmical cues, our results suggest that some visual language cues are subject to sensitive periods. On the other hand, some of the subjects in the late acquisition group did succeed at discriminating visual French from visual English. Thus, either some cues are subject to sensitive period effects and others are not, and the subjects differentially attended to these cues, or there are individual differences between the subjects such that some retain greater openness to non-native information than do others. Understanding this within group variability more deeply will be an important focus for future research. It will provide insight into the speech perception limitations faced by both first and second language learners, and provide guidance for improvement.

ACKNOWLEDGMENTS

This research was supported by Research grants from the Natural Sciences and Engineering Research Council (NSERC) and the Social Sciences and Humanities Research Council (SSHRC) to Janet F. Werker, by NSERC and SSHRC Fellowships to Whitney M. Weikum, and by grants PSI2009-12859, PSI2012-39149 and RYC-2008-03672 from Ministerio de Economia y Competitividad (Spanish Government), and the European COST action TD0904 to Jordi Navarra. Salvador Soto-Faraco was supported by ERC (STG-2010263145), MICINN (PSI2010-15426 and Consolider INGENIO CSD2007-00012) and AGAUR (SGR2009-092).

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 29 April 2013; accepted: 25 October 2013; published online: 13 November 2013.

Citation: Weikum WM, Vouloumanos A, Navarra J, Soto-Faraco S, Sebastián-Gallés N and Werker JF (2013) Age-related sensitive periods influence visual language discrimination in adults. Front. Syst. Neurosci. 7:86. doi: 10.3389/fnsys.2013.00086

This article was submitted to the journal Frontiers in Systems Neuroscience.

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APPENDIX

SENTENCE EXAMPLES FROM THE BOOK, LE PETIT PRINCE/ THE LITTLE PRINCE BY ANTOINE DE SAINT-EXUPERY

Sentence 1
English version- The little prince had watched very closely over this small sprout which was not like any other small sprout on this planet.

French version- Le petit prince avait surveillé de très près cette brindille qui ne ressemblait pas aux autres brindilles.

Sentence 2
English version- If the two billion inhabitants who people the surface were all to stand upright, all humanity could be piled up on a small Pacific islet.

French version- Si les deux milliards d’habitants qui peuplent la terre se tenaient debout et un peu serrés, on pourrait entasser l’humanité sur le moindre petit îlot du Pacifique.