INT J LANG COMMUN DISORD, JULY–AUGUST 2011,
VOL. 46, NO. 4, 411–422

Research Report

Speech perception in noise by monolingual, bilingual and trilingual listeners

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(*Received 18 January 2010; accepted 23 August 2010*)

Abstract

Background: There is strong evidence that bilinguals have a deficit in speech perception for their second language compared with monolingual speakers under unfavourable listening conditions (e.g., noise or reverberation), despite performing similarly to monolingual speakers under quiet conditions. This deficit persists for speakers highly proficient in their second language and is greater in those who learned the language later in life. These findings have important educational implications because the number of multilingual children is increasing worldwide, and many of these children are being taught in their non-native language under poor classroom acoustic conditions.
Aims: The performance of monolingual, bilingual and trilingual speakers on an English speech perception task was examined in both quiet and noisy conditions. Trilingual performance was compared with that of monolingual and bilingual speakers.
Methods & Procedures: Monolingual speakers of English and early bilingual and trilingual speakers (i.e., acquired English as a second/third language before the age of 6 years) were recruited. Their fluency in English was tested by interview and by a questionnaire assessing their knowledge and use of the language. Audiological evaluation confirmed normal hearing in all participants. English speech perception was tested in quiet and in different levels of noise (50, 55, 60, 65 and 70 dB SPL) using the Speech Perception in Noise (SPIN) Test.
Outcomes & Results: Bilingual and trilingual listeners performed similarly to monolingual listeners in quiet conditions, but their performance declined more rapidly in noise and was significantly poorer at 65 and 70 dB SPL. Trilingual listeners performed less well than bilinguals at these noise levels, but not significantly so. A subgroup of five bilingual speakers who learned Arabic and English simultaneously since birth were poorer at higher levels of noise than monolinguals, but not significantly so.
Conclusions & Implications: The results replicate previous findings of poorer speech perception in noise with bilingual speakers compared with monolinguals and extend the findings to trilingual speakers.

Keywords: speech perception in noise, bilingualism, trilingualism.

What this paper adds
Previous research has shown that bilingual speakers have poorer speech perception for their second language in noise than do monolinguals. This paper replicates this finding and, to the authors' knowledge, it is the first to extend the finding to trilingual speakers. The paper also alerts readers to more recent evidence that bilinguals also perform more poorly in their first language when listening in noise compared with monolinguals. Further analyses examine whether trilinguals show a greater listening disadvantage than bilinguals and compare performance by a small group of bilinguals who learned their languages simultaneously since birth with monolinguals.

Introduction

Poor classroom acoustics has been shown to have a deleterious effect on academic achievement and psycho-educational and psychosocial development (Crandell 1991 1992, 1993, Finitzo-Hieber 1988, Johnson 2000). High levels of reverberation (the persistence of sound after cessation of the source) and noise (unwanted sound inside or outside a room) negatively affect speech perception, reading and spelling ability, classroom attention, concentration, and educational achievement (American Speech–Language–Hearing Association

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International Journal of Language & Communication Disorders
ISSN 1368-2822 print/ISSN 1460-6984 online © 2010 Royal College of Speech & Language Therapists
DOI: 10.3109/13682822.2010.519372

(ASHA) 2005c). The ASHA (2005a: 1) recommends that:

> (1) Unoccupied classroom noise must not exceed 35 dBA; (2) The signal-to-noise ratio (SNR) should be at least +15 dB; and (3) Unoccupied classroom reverberation times must not surpass 0.6 seconds in smaller (<10,000 ft^3) or 0.7 seconds in larger classrooms.

These conditions are seldom met (e.g., Knecht *et al.* 2002). Typical classrooms have SNRs of −7 to +5 dB and reverberation times of 0.4 to 1.2 s (Blair 1977, Crandell 1992, Finitzo-Hieber 1988, Knecht *et al.* 2002). This has important implications, especially for children with special needs.

Crandell (1991, 1992) found that optimal speech perception requires at least a +6 dB SNR and <0.5 s reverberation time. Children with special needs may require more favourable SNRs and shorter reverberation times (ASHA 2005b). One group with 'special needs' is those taught in a non-native language. In the United Kingdom, 15.2% of children in primary schools speak a first language other than English. The percentage varies widely across the country. In Inner London, the mean is 54.1%, with some local authority areas having over 70% (Department for Children, Schools and Families (DCSF) 2010). In the United States it is estimated that by 2010 one of five schoolchildren will be a recent immigrant and many will speak languages other than English at home (US Bureau of the Census 2000).

Many studies have shown that non-native speakers of English have more difficulty perceiving speech in noise and reverberation than native speakers (Buus *et al.* 1986, Caramazza *et al.* 1973, Crandell and Smaldino 1996, Florentine 1985a, 1985b, Florentine *et al.* 1984, McAllister 1990, Mayo *et al.* 1997, Nabelek and Donahue 1984, Rogers *et al.* 2006, Takata and Nabelek 1990). In these studies non-native speakers performed as monolinguals in quiet conditions, but had lower noise tolerance levels, demonstrated decreased performance on speech recognition tasks as signal-to-noise conditions deteriorated, and were less able to benefit from across-word contextual information.

Reasons for these performance decrements has been attributed to a number of factors, including degree of exposure to the language, age of second-language acquisition and adversity of the listening environment. For example, Florentine (1985b) found that while non-native listeners' ability to understand English speech in noise improved as their exposure to the language increased, only two non-native listeners with exposure to English since infancy performed like native listeners, when assessed with the Speech Perception in Noise (SPIN) test (Bilger *et al.* 1984, Kalikow *et al.* 1977). Florentine suggested that a sensitive period for second-language acquisition may exist. Mayo *et al.* (1997) explored whether age of second-language acquisition influences English speech perception by comparing early bilinguals (before 6 years of age) and late bilinguals (after age 14) with monolingual speakers using the SPIN test. Having shown that their groups did not differ in quiet conditions, they tested them in noise first at 55 dB SPL then at increments of 5 dB to find a level at which subjects' speech perception scores reached 50% accuracy. Bilinguals with early acquisition of English performed better than those with later acquisition but were poorer than monolinguals. Three bilingual listeners had learned their languages simultaneously since infancy. Though too small a group for comparisons, Mayo *et al.* felt their performance was more similar to that of the early bilinguals than to monolinguals.

Rogers *et al.* (2006) obtained similar results using the Speech Intelligibility Gain—Reverberant (SIG-R) test (Koehnke and Besing 1996). They compared the performance of monolinguals with bilinguals who had learned English before 6 years of age, had no discernible accent and half of whom rated their English as superior to their first language (Spanish). While bilinguals' perception of English speech in quiet was similar to monolinguals, their performance in noise and/or reverberation was, nevertheless, inferior. Again, only three participants had learnt their languages simultaneously, which is too small a number to detect if they differed from monolinguals.

These results suggest that early acquisition is important, but it remains unclear whether a sensitive period exists for second-language acquisition or whether bilinguals can ever perform as well as monolinguals in their second language. This view, that a sensitive period exists, may reflect the widely accepted perspective that it exists for language learning generally (Johnson and Newport 1989). The difficulty of finding and verifying the language status of individuals with very early bilingualism may be frustrating for researchers in this area and may have contributed to the recent adoption of a different approach. This involves comparing bilinguals' perception in noise of their first language with that of monolinguals. Demonstration that bilinguals are poorer than monolinguals in their first, as well as their second, language would suggest that bilingualism has a general effect on language processing. Some results have been consistent with this suggestion. Weiss and Dempsey (2008) showed that bilinguals with greater experience of their second language were poorer at perceiving their first language in noise. This suggests that the problem increases as the participants became more proficiently bilingual. Von Hapsburg and Bahng (2008) also found that perception in noise of their participants' first language (Korean) deteriorated as their proficiency in English increased. These findings suggest that bilingualism may generally impair speech perception in demanding conditions. This might arise because the demands made on a listener's perceptual skills by two different languages limits their ability in either language, a deficit which is revealed under adverse listening conditions. It might also arise because proficient bilinguals use both their languages and, as a result, have less exposure to either than do monolinguals.

This study uses the original methodology of testing participants in their later acquired language but extends it to include both early bilingual and trilingual participants.[1] In line with previous results, we expect both multilingual groups to show impaired perception of English in noise compared with monolinguals. A further interest is whether trilinguals have a greater deficit than bilinguals. Such a result would add to evidence that multilingualism generally has an effect on speech perception, and would highlight the importance of controlling acoustic conditions in classrooms and other learning environments so that speech understanding by non-native students is optimized.

Methods

Three groups of adult listeners were recruited from the faculty, staff and student body of the American University of Beirut, and from students of other local universities. One group consisted of monolingual English speakers, one of bilinguals who were fluent in Arabic (native language) and English (second language), and one of trilingual's who spoke Arabic, French and English fluently. The latter considered Arabic and French to be their native and second languages and English to be their third language.

Multilingual participants who were highly fluent in English were sought. Attempts were made to control for factors known to influence speech perception in multilingual samples, namely: (1) age of second or third-language acquisition, (2) duration of second or third-language study, and (3) degree of second or third-language usage and exposure. Participants' English was assessed by their fluency and extent and proficiency of its use. First, a speech–language pathologist and native English speaker assessed participants' fluency during a face-to-face interview in which they answered questions about everyday activities and events. Only participants judged as highly fluent were selected for further assessment. This consisted of a questionnaire (see the appendix) with 35 questions examining language usage, fluency and exposure. Only participants who (1) learned English before the age of 6 years (as in Mayo *et al.* 1997), (2) received more than 5 years of formal education in English, (3) rated themselves fluent or very fluent in written and spoken English, (4) spent more than 50% of their time reading, listening to music, or watching television and films in English, and (5) communicated in English more than 25% of the time were included.

Participants underwent an audiological evaluation. They had no recent history of otologic pathology. Pure tone audiometry revealed air-conduction thresholds better than 15 dB HL from 0.25 to 8 kHz in octave steps (American National Standards Institute (ANSI) 1989), and hearing symmetry at each test frequency (interaural threshold differences at each test frequency were ≤ 5 dB). Immittance testing revealed a normal tympanogram in each ear (Type A), and present ipsilateral and contralateral acoustic reflexes, bilaterally (Jerger and Hayes 1980).

All selected participants worked or studied in Beirut, Lebanon, and held a college degree (undergraduate or graduate) or were undergraduate students. College courses were taught in American English.

The monolingual group (ML) of nine listeners (male = 2, female = 7) learned English from birth and had no other language. They ranged in age from 22 to 40 years (mean = 30 years; standard deviation (SD) = 5.2), had received more than 15 years of formal education in English (mean = 17.2 years; SD = 1.7). They communicated solely in English and rated themselves very fluent readers and writers of English.

The bilingual group (BL) of 13 listeners (male = 5, female = 8) were aged from 18 to 35 years (mean = 27 years; SD = 5.1). All had been exposed to Arabic from birth and to English before the age of 5 years (mean = 2.1 years; SD = 1.9). All had received 10–17 years of formal education taught in English (mean = 12.3 years; SD = 1.5).

The trilingual group (TL) of 12 listeners (male = 5, female = 7) aged from 21 to 32 years (mean = 26.5 years; SD = 4.0). All learned Arabic and French first, and were introduced to English between 3 and 6 years of age (mean = 4.5 years; SD = 1.0 years). All had 6–15 years of formal education in English (mean = 10.5 years; SD = 3.4 years). As in the BL group, they had significant exposure to and usage of English.

Test materials and apparatus

Participants were tested with the revised version of the Speech Perception in Noise (SPIN) test (Bilger *et al.* 1984). The test has eight lists of 50 sentences ending in a target word and presented in a 12-talker babble noise. Targets are monosyllabic nouns. Half are predictable from the context of the sentence (e.g., *The cabin was made of logs.*) and half are embedded in syntactically correct sentences with no contextual cues (e.g., *I should have known about the gum.*). The test allows a comparison between a listener's use of contextual cues in speech (high-predictability sentences) and his/her use of acoustic–phonetic information (low-predictability sentences).

Testing required a portable compact disc (CD) player that played recordings of the SPIN sentences and multi-talker noise. Output from the player was routed to a two-channel audiometer (Interacoustics AC 40), with the target sentences and background noise in channels 1 and 2 of the audiometer, respectively. Outputs from both channels were mixed and directed to both transducers of standard audiometric earphones to create a diotic listening condition. Prior to testing participants, a precision sound level meter (Bruel & Kjaer, Type 2231) was used to calibrate each channel separately to achieve an average level of 70 dB SPL ($\pm$2 dB) for target words of the SPIN sentences. Similarly, the level of the multi-talker noise was calibrated to achieve an average level of 70 dB SPL ($\pm$2 dB) in each earphone transducer. Additionally, audiometer intensity (linearity) was checked to assure that multi-talker noise levels of 50, 55, 60, 65 and 70 dB SPL were accurate and achievable upon audiometer potentiometer manipulation. All calibration measures and experimental testing were conducted in the same double-walled, sound-treated, acoustic chamber (IAC).

Sentences were presented at a constant level of 70 dB SPL. The level of noise varied from 50 to 70 dB SPL, in 5-dB steps. As determined during pilot testing, this range allowed speech perception performance to vary between less than 15% accuracy (in 70 dB SPL noise) to more than 85% accuracy (in 50 dB SPL noise).

Procedure

The experiment was conducted during a single, 2-h session. Mandatory rest periods were provided every 30 min (or sooner if requested). Participants signed consent forms and completed the English fluency assessment and language questionnaire. Next, they were given written and verbal instructions about the SPIN test. Initially all participants were tested in a quiet listening environment (i.e., noise absent), using sentences from SPIN list 4 presented at 70 dB SPL. After each sentence, participants wrote down the target word and reported it verbally to the experimenter, who also wrote it down. As in Mayo *et al.* (1997), testing was discontinued if the first 25 targets were correct and a score of 100% was obtained for the quiet condition. Otherwise, all 50 sentences were presented and the score (as a percentage) was the number of words correctly reported. As a further check upon participants' ability in English, it was proposed to exclude anyone who scored less than 96% in the quiet condition. This proved unnecessary as all participants exceeded this target. Speech perception in noise was assessed using lists 1, 3, 5, 6, 7 and 8 of the SPIN test. Six noise levels (50, 55, 60, 65 and 70 dB SPL and one 'individual' level) were used so that a psychometric function for speech perception in noise could be constructed for each participant. Word list and noise level order were randomized across listeners. The five standard noise levels were tested, followed by the individual noise level.

The 'individual' noise level was used to help refine the psychometric function, so that the point where discrimination was about 50% could be identified more readily. For example, if a listener scored 35% with noise at 65 dB SPL and 70% at 60 dB SPL, the 'individual' level was set three decibels higher than the lower standard noise levels (i.e., 63 dB SPL; increments less than 1 dB could not be made with the audiometer used). Refinement of the psychometric function was required for an estimation of *noise tolerance level*, which is defined here as the level of noise that could be tolerated before a listener's performance dropped below 50% accuracy.

Results

Speech perception scores (%) for the full list of SPIN words and for high- and low-predictability sentences at four standard noise levels (i.e., 55, 60, 65, and 70 dB SPL) were calculated for each listener (data from 50 dB SPL were not included in the analysis as not all participants completed this level). Mean scores for the ML, BL and TL groups at each noise level are shown in table 1. A three-factor mixed analysis of variance was conducted. Language was a between-subject variable with three levels (ML, BL, TL). Sentence predictability with two levels (low, high) and noise with four levels (55, 60, 65 and 70 dB SPL) were within-subject variables.

There were significant main effects for each variable: language [$F(2, 31) = 8.34$, $p < 0.01$], sentence predictability [$F(1, 31) = 363.28$, $p < 0.0001$] and noise level [$F(3, 93) = 794.09$, $p < 0.0001$]. The advantages for high (69%) over low (52%) predictability sentences and for noise level were expected. A Newman–Keuls test showed that all noise levels differed significantly from each other ($p < 0.01$). The main effect of language reflected the differing performance of the ML (68.12%), BL (59.73%) and TL (55.75%) groups. Planned comparisons found that monolinguals were significantly better than bilinguals ($p < 0.05$) and trilinguals ($p < 0.001$), but that the latter groups did not differ significantly.

The main effect of language was qualified by a significant interaction between language and noise level [$F(6, 93) = 3.90$, $p < 0.01$]. An analysis of simple main effects showed that differences existed between monolinguals and the other groups at the higher levels of noise (65 and 70 dB SPL). These results replicate previous findings that in adverse conditions bilingual (and now trilingual) listeners perform more poorly than

Table 1. Mean percentage accuracy and standard deviations (SD) for monolingual, bilingual and trilingual participants at each level of noise

		Noise level (dB SPL)				
Language group	*n*	55	60	65	70	*p*-value
Monolingual	9	95.11 (2.27)	87.78 (7.09)	70.67 (6.52)	19.11 (3.24)	<0.0001
Bilingual	13	89.69 (6.14)	83.07 (10.78)	56.15 (10.78)	10.00 (5.05)	<0.0001
Trilingual	12	89.00 (4.22)	79.50 (9.64)	45.83 (9.13)	8.67 (5.69)	<0.0001
		n.s.	n.s.	$p < 0.01$	$p < 0.05$	

Note: n.s., Not significant.

monolingual listeners. At lower levels of noise no listening disadvantage was seen.

The interaction between sentence predictability and noise was also significant [$F(3, 31) = 42.29$, $p < 0.0001$]. Mean scores are shown in table 2. Simple main effects showed that predictability had a significant effect at all noise levels except 70 dB SPL. This suggests that a 'floor effect' exists for the 70-dB SPL condition reducing the difference between high- and low-predictability sentences.

Five bilingual speakers had learned Arabic and English simultaneously since birth. Their data and that of the other bilinguals and the monolinguals are shown in table 3. At higher noise levels they perform midway between the other bilinguals and the monolinguals. However, analysis showed that they did not differ significantly from either of the other groups.

Noise tolerance levels (dB) for individual listeners were analysed using a two-factor mixed analysis of variance (ANOVA). The mean noise tolerance level was 66.5 dB SPL (SD = 1.69) for monolinguals, 64.78 dB SPL (1.40) for bilinguals and 63.63 dB SPL (1.52) for trilinguals. Language was a between-subject variable with three levels (ML, BL, TL), and sentence predictability was a within-subject variable with two levels (low, high). There were significant main effects for language [$F(2, 31) = 12.26, p < 0.01$] and predictability [$F(1, 31) = 180.78$, $p < 0.001$]. Planned comparisons showed that the former was due to higher noise tolerance levels in monolinguals than either bilingual ($p < 0.01$) or trilingual ($p < 0.01$) listeners. The difference between bilinguals and trilinguals was just short of significance ($p < 0.07$). The language × predictability interaction was not significant ($p > 0.05$).

The majority (more than 75%) of speech perception errors made by participants were substitutions or omissions of final consonants. This was especially true for high-frequency fricatives and unvoiced stops. Examples include cliff → clip (substitution), cheers → cheer (omission) and fleet → feet (reduced cluster/blend). The remaining errors (including random guesses and no responses) typically occurred in the poorest listening conditions, and are likely the result of significant spectral/temporal interactions between the target word and background noise (i.e., masking), resulting in decreased linguistic and extra-linguistic

Table 2. Mean percentage accuracy and standard deviations (SD) for high and low predictable sentences at each level of noise

	Noise level (dB SPL)				
SPIN words	55	60	65	70	*p*-value
High predictability	96.71 (3.75)	94.23 (5.24)	71.29 (10.95)	13.64 (6.86)	<0.0001
Low predictability	85.06 (6.84)	71.88 (12.53)	41.41 (9.45)	10.23 (4.57)	<0.0001
	$p < 0.0001$	$p < 0.0001$	$p < 0.0001$	n.s.	

Note: n.s., Not significant.

Table 3. Mean percentage accuracy and standard deviations (SD) for monolingual, bilingual since birth and other bilinguals at each level of noise

		Noise level (dB SPL)			
Language group	*n*	55	60	65	70
Monolingual	9	95.11 (2.27)	87.78 (7.09)	70.67 (10.81)	19.11 (3.24)
Bilingual since birth	5	92.80 (3.63)	88.80 (10.78)	61.60 (7.40)	12.40 (1.67)
Other bilingual	8	87.75 (6.96)	77.50 (9.64)	52.75 (16.10)	8.75 (12.23)

redundancy (e.g., Florentine 1985a, Mayo *et al.* 1997, Rosenhouse *et al.* 2006).

Discussion and conclusions

There is increasing evidence that bilingual speakers may experience speech-perception difficulties under adverse listening conditions compared with monolingual speakers, while performing similarly in quiet conditions (e.g., Buus *et al.* 1986, Florentine 1985a, Mayo *et al.* 1997, Rosenhouse *et al.* 2006). The results of this study support previous findings. That is, while the monolinguals and bilinguals performed equally in quiet conditions, bilingual speakers showed greater speech-perception difficulties in noise when signal-to-noise conditions were poor (i.e., when the SNR is zero or +5 dB). Importantly, the results of the study suggest that this finding may be extended to trilingual speakers, who performed similarly to bilinguals. Although trends in the data suggest that speech-perception deficits declined more rapidly in noise for trilinguals compared with bilinguals, these differences did not reach statistical significance.

To our knowledge there are no previous studies of performance of trilingual speakers on speech perception in noise tasks. The multilingual environment of Lebanon lends itself to research of this kind. Speakers of two or three languages are common because many children begin formal education at 3 years of age and attend schools which teach in English and French (strict monolinguals are less available!). Our participants all learned their languages before 6 years of age, thus confirming findings (Mayo *et al.* 1997, Rogers *et al.* 2006) that listeners with early acquisition and high levels of proficiency are affected.

Currently, two views on speech-perception deficits by bilingual speakers under adverse listening conditions appear in the literature. The longstanding view is that proficient bilinguals will have difficulty in their second language. Several studies have shown that when tested in their second language (usually English), bilinguals perform like monolinguals in quiet conditions but show greater deterioration under adverse listening conditions (Caramazza *et al.* 1973, Crandell and Smaldino 1996, Florentine 1985a, 1985b, Florentine *et al.* 1984, McAllister 1990, Mayo *et al.* 1997, Rogers *et al.* 2006, Rosenhouse *et al.* 2006). These findings have raised concerns that the increasing number of children taught in a second language may be handicapped if attending schools with poor classroom listening environments. The studies also found a greater disadvantage when the second language is acquired later in life. As a result, it is often assumed that very early or simultaneous acquisition of a second language will not cause a disadvantage in speech perception ability. This issue appears unresolved perhaps because of the difficulty of finding sufficient numbers of bilinguals with very early acquisition of both languages.

An alternative and more recent view is that bilingualism itself is the culprit and that the speech perception problems are not limited to second or later acquired languages. It was raised by Von Hapsburg and Pena (2002) in a review of speech audiometry with bilingual subjects. They suggested that bilinguals will perform more slowly in reaction time tasks and less accurately in noise, due to a need, even in a monolingual task, to search both their lexicons. Experimental evidence in support of this view is now available from the studies by Weiss and Dempsey (2008) and Von Hapsburg and Bahng (2008), and Carlo (2008) has alerted audiologists who may increasingly be required to test bilingual subjects. If confirmed, this would increase the number of children who experience speech perception problems in noisy classrooms.

This alternate view, that bilingual speech perception is generally impaired under adverse conditions, does not assume that a sensitive period exists and expects that even those individuals who are bilingual from birth will be impaired when compared with monolinguals. Previous studies had few participants of this kind. Mayo *et al.* (1997) included only three and found their performance to be more similar to that of the later acquired bilinguals. Rogers *et al.* (2006) appear to have felt the same as their analyses combined their participants with very early and later acquisition. In the present study, five participants were bilingual since birth. Their performance was between that of monolinguals and other bilinguals at higher noise levels but did not differ significantly from either. Again, it appears, there were too few participants to resolve whether a sensitive period for acquisition exists or whether all bilinguals perform worse than monolinguals in noise.

Earlier researchers, while detecting a speech-perception deficit in bilinguals, have been undecided on its cause. Perceptual causes might include maintenance of attention for the presented language or the need to select appropriate phonemes from a larger set of potential targets or to search both their lexicons, as suggested by Von Hapsburg and Pena (2002). Added to these are environmental factors such as the diminished use of any of their languages compared with monolinguals. These explanations suggest that the problem experienced in noise by multilingual speakers may increase with the number of languages they use and that this, rather than the order or time of acquisition, causes the problems in adverse listening conditions. In the present study, the results are intriguing but not convincing. Trilinguals had a greater deficit than bilinguals, but not significantly so. Their noise tolerance level was also lower but was just short of significance.

Perceptual studies offer some clues about the problems bilingual and trilingual speakers may face. Bosch and Sebastian-Galles (2003) and Sebastian-Galles and Bosch (2009) studied vowel contrasts present in Catalan but not Spanish. At 4 months of age, infants in Catalan, Spanish and bilingual environments all perceived the contrast. At 8 months, Catalan infants were successful, but Spanish infants were not. Surprisingly bilinguals were also unsuccessful. Hence, exposure to Spanish appears to impair a skill normally present in Catalan speakers. However, the delay is short-lived. By 12 months of age, the bilinguals had regained the ability. Evidence of a longer-lasting effect is available in Sundara *et al.* (2006). Here an English contrast was tested and French monolingual and English/French bilingual children were shown to be significantly poorer than English monolinguals at 4 years of age. Sundara *et al.* also report data from adults. Here the French but not the bilingual speakers were significantly poorer than English speakers, suggesting that the deficit had been overcome. This result is not entirely convincing, however. The scores for the bilingual group were between the two monolingual groups and do not differ significantly from either. Moreover, the standard deviation of the bilingual group was large, suggesting that at least some had difficulty making the discrimination. In a further study, Sundara and Polka (2008) showed that adult simultaneous bilinguals did not differ from monolingual English speakers in perceiving coronal stops, but that bilinguals who learned their second language when entering school at age 5 years did, a result consistent with the view that the time of acquisition is important and that a critical early period for acquisition may exist.

There is also evidence that early bilingualism may affect the lateralization of language. Hull and Vaid (2006, 2007) conducted a meta-analysis of laterality studies comparing monolinguals and bilinguals. Monolinguals and late bilinguals (a second language learnt after 6 years of age) showed left hemisphere dominance for both languages, while early bilinguals (before age 6 years) showed bilateral representation of both languages. In the late group, language proficiency is associated with stronger left hemisphere dominance. The relevance of these results to speech perception is strengthened by the fact that they are particularly strong in dichotic listening experiments. Thus, proficient speakers with early acquisition of their languages—the type studied here—may have bilateral hemispheric representation. In contrast, proficient but late acquisition of a second language appears to build upon left hemisphere dominance that exists for the first language. Thus, the late bilingual group in Mayo *et al.* (1997), the members of which acquired their second language after age 14 years and who showed a significantly greater decline in performance with noise, may also have a different pattern of lateralization than their early group.

Critics might argue that deficits in a second or third language are an inevitable consequence of a preference for an earlier learned language and that any further deficit shown by trilinguals compared with bilinguals is a reflection of the marginal status of their third language. As in other studies of this kind, efforts were made to ensure this was not the case. Participants had extensive experience of English and used it a high proportion of the time and in varying contexts. The findings also replicate previous studies where multilingual participants demonstrated speech-perception deficits in noise. At lower noise levels (55 and 60 dB SPL) the groups perform equally. Although the task is not especially difficult at low noise levels, it should be noted that the equal performance across the groups was not a result of a ceiling effect. Participants in each group made some errors even in the quieter conditions. The results of Rogers *et al.* (2006) are also persuasive here. Their bilinguals were highly proficient in English, their second language, spoke it without an accent and regarded it as their dominant language, yet the deficit in noise remained. This finding is consistent with both the views outlined above. It may mean that a second language is impaired because of its later acquisition, however proficient it becomes. Alternatively it may suggest that bilinguals' languages are all impaired regardless of the order in which they are learned or the level of dominance they attain. Testing of similar subjects in their first but now less dominant language (as well as their second language) would resolve the issue.

Until recently, bilinguals' impaired perception in noise appeared to be non-contentious. Their impairment was clearly demonstrated as was the relative benefit of early acquisition and experience. The proposal that a sensitive period for learning a second language existed provided some explanation of the effect. Languages would be impaired when learnt beyond that period or when they were less proficient than the first. Failures to show conclusively that either very early acquisition or high levels of proficiency and usage in a second language overcome the problem have led some to doubt this view; recent evidence that first languages are also impaired has confused it. It now appears that the quantity of languages may be more important than their quality or their age of acquisition. The findings reported here are suggestive but far from conclusive. The traditional call for further research, on this occasion, appears justified. Increasing linguistic diversity offers promise for such research, although even in favourable language learning environments such as Lebanon, it may be difficult to find sufficient numbers of subjects with high levels of fluency in a third language or with simultaneous acquisition of their languages.

Researchers in this area have drawn attention to the problems that may be experienced by children learning in a second language in noisy schools. The findings here unsurprisingly extend this concern to children with more than two languages. A further concern is that the numbers of children involved are rapidly increasing. If, as recent research suggests, the deficit in noise is present for all the languages that children speak this number will increase yet further. These findings justify concern about the education of minority groups, and highlight the need for school administrators and teachers to ensure optimal classroom listening environments for their non-native students.

Note

1. Arabic is unusual in having distinct spoken and written forms. The spoken form exists in various dialects, some differing substantially. Literary Arabic is used in formal and written communication. There is experimental evidence from priming studies (Ibrahim and Aharon-Peretz 2005, Ibrahim 2009) for the cognitive independence of the two forms. A reviewer suggested that the bilingual and trilingual speakers in this paper might, therefore, be referred to as trilingual and quadrilingual. We acknowledge this, but felt that doing so in the text might be confusing.

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Appendix: Language background questionnaire

Table A1.

Language Group	#	Question
All	1	What is your age? ______ (years)
All	2	What language do you consider as your primary ("Mother") language? ☐ Arabic ☐ English ☐ French ☐ Other ______________ (name of language)
All	3	Are you fluent in more than one language? ☐ No ☐ Yes If Yes, do you consider yourself as a Bilingual or Trilingual? ☐ Bilingual ☐ Trilingual
BL	4	Do you consider yourself as a "bilingual", with Arabic and English as the languages you know? ☐ No ☐ Yes
TL	4	Do you consider yourself as a trilingual, with English as your 3rd language? ☐ No ☐ Yes
BL	5	At what age did you start learning each of the following languages: Arabic ______ (age) English______ (age)
TL	5	At what age did you start learning each of the following languages: Language 1: Name of Language _______________ ______ (age) Language 2: Name of Language ________________ ______ (age) Language 3: English ______ (age)
BL	6	Since what age do you consider yourself as "bilingual"? ______ (age)
TL	6	Since what age do you consider yourself as "trilingual"? ______ (age)
All	7	Where did you learn English (Check all that apply)? ☐ At home ☐ At school ☐ At work ☐ Other __________________________ (list)
All	8	What type of English did you learn? ☐ American English ☐ British English
BL	9	In which language do you consider yourself most fluent verbally (check one)? ☐ Arabic ☐ English ☐ I am equally fluent in both
TL	9	In which language do you consider yourself most fluent verbally (check one)? Language #1: ______________ (name of language) Language #2: ______________ (name of language) Language #3: ENGLISH I am equally fluent in: __________________________ (list)
BL	10	In which language do you understand (comprehend) best? ☐ Arabic ☐ English ☐ I understand both languages equally
TL	10	In which language do you understand (comprehend) best? Language #1: ______________ (name of language) Language #2: ______________ (name of language) Language #3: ENGLISH I am equally fluent in: __________________________ (list)
ML	11	When communicating with others (verbally and in writing), do you use English 100% of the time? ☐ No ☐ Yes If no, please explain: ____
BL, TL	11	When communicating with others (verbally and in writing), what percentage of the time, during a typical day, do you communicate in English? ☐ $<$ 10% ☐ 25% ☐ 50% ☐ 75% ☐ $\geq$ 90%
BL	12	When communicating with others (verbally and in writing), what percentage of the time, during a typical day, do you communicate in Arabic (Mother language)? ☐ $\leq$ 10% ☐ 25% ☐ 50% ☐ 75% ☐ $\geq$ 90%

Table A1 – *continued*

Language Group	#	Question
TL	12	When communicating with others (verbally and in writing), what percentage of the time, during a typical day, do you communicate in your 1^{st} (Mother) language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% When communicating with others (verbally and in writing), what percentage of the time, during a typical day, do you communicate in your 2^{nd} language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ > 90%
BL, TL	13	At what age did you begin learning to speak: Language #1: ____________________ (name of language) _____ (age) Language #2: ____________________ (name of language) _____ (age) Language #3: ENGLISH _____ (age) *trilinguals only*
BL, TL	14	At what age did you begin learning to write: Language #1: ____________________ (name of language) _____ (age) Language #2: ____________________ (name of language) _____ (age) Language #3: ENGLISH _____ (age) *trilinguals only*
All	15	Where were you born? _________________________________ (City & Country) If you were born outside of Lebanon, how long did you live there after birth? _____ (years)
All	16	How many years have you resided in Lebanon? _____ (years)
All	17	Have you lived in any other countries other than your country of birth and/or Lebanon? ☐ No ☐ Yes If Yes, which countries and for how many years? ___________________ Country _____ (years) ___________________ Country _____ (years) Did you learn the language(s) of the country *(answer only if the language was other than English or Arabic)*? ☐ No ☐ Yes If Yes, rate your fluency in the language? Language #1 _____________ (name of language): ☐ Not fluently ☐ Fluently ☐ Very Fluent Language #2 _____________ (name of language): ☐ Not fluently ☐ Fluently ☐ Very Fluent
All	18	Were your parents/caregivers born and raised in Lebanon? Mother: ☐ No ☐ Yes If no, which country? _____________________ Father: ☐ No ☐ Yes If no, which country? _____________________ Caregivers: ☐ No ☐ Yes If no, which country? _____________________
All	19	What language(s) did you speak in the house with your parents/caregivers? Mother: _____________ (name of language) Father: _____________ (name of language) Caregivers: _____________ (name of language)
All	20	Do you read books? ☐ No ☐ Yes If yes, are 100% of the books written in English: ☐ No ☐ Yes *monolinguals only* If yes, what percentage of books are written in English? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
All	21	Do you read magazines? ☐ No ☐ Yes If yes, are 100% of the magazines written in English: ☐ No ☐ Yes *monolinguals only* If yes, what percentage of magazines are written in English? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
All	22	Do you listen to the radio? ☐ No ☐ Yes If yes, are 100% of radio stations English-presenting: ☐ No ☐ Yes *monolinguals only* If yes, what percentage of the radio stations are English-presenting? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
All	23	Do you listen to CDs or tapes? ☐ No ☐ Yes If yes, are 100% of the CDs/tapes in English: ☐ No ☐ Yes *monolinguals only* If yes, what percentage of the CDs/tapes are in English? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
All	24	Do you watch English films? ☐ No ☐ Yes If yes, are 100% of the films in English: ☐ No ☐ Yes *monolinguals only* If yes, what percentage of the films are in English (without subtitles)? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%

Table A1 – *continued*

Language Group	#	Question
BL, TL	25	Are there situations where you speak English only? ☐ No ☐ Yes If yes, please state when: ______________________________
All	26	How would your rate your English reading ability? ☐ Not fluently ☐ Fluently ☐ Very Fluent
All	27	How would you rate your English writing ability? ☐ Not well ☐ Well ☐ Very Well
All	28	What is your educational language background (Check all that apply)? ☐ Grade School Primary Language of Instruction: ______________ # years: ______ ☐ High School Primary Language of Instruction: ______________ # years: ______ ☐ College Primary Language of Instruction: ______________ # years: ______ ☐ Post-Graduate Primary Language of Instruction: ______________ # years: ______
All	29	In summary, what is the total number of years that you have had formal teaching of English? ______ (years)
All	30	At work/university, what languages do you use (List)? ______________ ______________ ______________
ML	31	At work/university, do you communicate verbally 100% of the time in English? ☐ No ☐ Yes If no, please explain: ______________________________
BL, TL	31	At work/university, what percentage of the time do you communicate verbally in your 1st (Mother) language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% At work/university, what percentage of the time do you communicate verbally in your 2nd language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% At work/university, what percentage of the time do you communicate verbally in your 3rd language (English)? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% *(Trilinguals only)*
ML	32	At work/university, do you communicate in writing 100% of the time in English? ☐ No ☐ Yes If no, please explain: ______________________________
BL, TL	32	At work/university, what percentage of the time do you communicate in writing in your 1st (Mother) language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% At work/university, what percentage of the time do you communicate in writing in your 2nd language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% At work/university, what percentage of the time do you communicate in writing in your 3rd language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% *(Trilinguals only)*
All	33	In your spare time Outside of work/university (in your spare time), what languages do you use (List)? ______________ ______________ ______________
ML	34	Outside of work/university, do you communicate verbally 100% of the time in English? ☐ No ☐ Yes If no, please explain: ______________________________ Outside of work/university, what percentage of the time do you communicate verbally in your 1st (Mother) language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
BL, TL	34	Outside of work/university, what percentage of the time do you communicate verbally in your 2nd language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% Outside of work/university, what percentage of the time do you communicate verbally in your 3rd language (English)? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% *(Trilinguals only)*
ML	35	Outside of work/university, if you need write (letters, notes, e-mails, etc.), do you communicate in writing 100% of the time in English? ☐ No ☐ Yes If no, please explain: ______________________________ Outside of work/university, if you need write (letters, notes, e-mails, etc.), what percentage of the time do you communicate in writing in your 1st (Mother) language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90%
BL, TL	35	Outside of work/university, if you need write (letters, notes, e-mails, etc.), what percentage of the time do you communicate in writing in your 2nd language? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% Outside of work/university, if you need write (letters, notes, e-mails, etc.), what percentage of the time do you communicate in writing in your 3rd language (English)? ☐ ≤ 10% ☐ 25% ☐ 50% ☐ 75% ☐ ≥ 90% *(Trilinguals only)*