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PAPER

Bilingual enhancements have no socioeconomic boundaries

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Abstract

To understand how socioeconomic status (SES) and bilingualism simultaneously operate on cognitive and sensory function, we examined executive control, language skills, and neural processing of sound in adolescents who differed in language experience (i.e. English monolingual or Spanish-English bilingual) and level of maternal education (a proxy for SES). We hypothesized that experience communicating in two languages provides an enriched linguistic environment that can bolster neural precision in subcortical auditory processing which, in turn, enhances cognitive and linguistic function, regardless of the adolescent's socioeconomic standing. Consistent with this, we report that adolescent bilinguals of both low and high SES demonstrate more stable neural responses, stronger phonemic decoding skills, and heightened executive control, relative to their monolingual peers. These results support the argument that bilingualism can bolster cognitive and neural function in low-SES children and suggest that strengthened neural response consistency provides a biological mechanism through which these enhancements occur.

Research highlights

- Language experience and socioeconomic status (SES) simultaneously influence cognitive and auditory sensory functions.
- The influences of bilingualism and SES are present during adolescence, a period in which cognitive and auditory systems are still developing.
- Both bilingualism and high SES contribute to gains in auditory neural function, and bilingualism enhances executive control and phonological processing, regardless of SES.

Introduction

Early research investigating the effect of bilingualism on intelligence painted a bleak picture for the polyglot. Numerous studies concluded that knowledge of more than one language results in confusion that permeates every facet of cognition (reviewed in Peal & Lambert, 1962), providing the basis for the long-standing belief that the mental abilities of bilingual children were inferior to monolingual children (Saer, 1923; Smith, 1923). Recent research has instead shown a more nuanced story: rather than finding overwhelmingly negative consequences of bilingualism, new findings point to both advantages and disadvantages of knowing more than one language. For example, when compared to monolinguals, bilinguals often demonstrate a smaller within-language vocabulary size (Bialystok, Luk, Peets & Yang, 2010), but also show enhancements in cognitive functions, including executive control of attention (Bialystok, 2009; Carlson & Meltzoff, 2008) and have more robust sensory processing (Bialystok & DePape, 2009; Krizman, Marian, Shook, Skoe & Kraus, 2012). Nevertheless, it is still highly debated whether these advantages outweigh the disadvantages of bilingualism, especially with regard to their impact on educational outcomes (Hoff, 2013).

Compounding the debate is that a disproportionate number of bilingual speakers come from socioeconomically impoverished backgrounds, especially within the

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United States (de Abreu, Cruz-Santos, Tourinho, Martin & Bialystok, 2012; Fennelly, 2005; Haskins, Greenberg & Fremstad, 2004; Hernandez, 2004). It has been repeatedly shown that low socioeconomic standing (SES) can have negative consequences for cognition and sensory processing (D'Angiulli, Herdman, Stapells & Hertzman, 2008; Hackman, Farah & Meaney, 2010; Neville, Stevens, Pakulak, Bell, Fanning *et al.*, 2013; Noble, McCandliss & Farah, 2007; Noble, Houston, Kan & Sowell, 2012; Raizada & Kishiyama, 2010; Skoe, Krizman & Kraus, 2013; Stevens, Lauinger & Neville, 2009), which can, in turn, adversely influence educational outcomes (Brooks-Gunn & Duncan, 1997). A major contributing factor to these negative consequences of low SES is an underdeveloped language system and subsequently weaker language skills (Durham, Farkas, Hammer, Tomblin & Catts, 2007). This effect on language skills is thought to stem from an impoverished linguistic environment in which children from low-SES families hear fewer and simpler words from their caregivers than their higher-SES peers (~30 million fewer words by age 3) (Hart & Risley, 1995). Given this sizeable difference in language exposure, it has been suggested that linguistic experience and its influence on the development of language, cognition, and sensory processing is a point of origin for the ever-widening, lifelong achievement gap between low- and high-SES individuals (Durham *et al.*, 2007; Hoff, 2013).

Although the influences of SES or bilingualism on linguistic, cognitive, and sensory function have separately been well characterized, few studies have looked at how they interact within an individual to shape language and cognition (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; de Abreu *et al.*, 2012) and their combined influence on sensory processing is virtually unknown. Therefore, the current study examined how socioeconomic status and bilingualism combine within an individual to influence sensory, linguistic, and cognitive function. We hypothesize that while the linguistic deprivation associated with low SES can lead to poorer sensory processing and undertrained language and cognitive systems, acquisition of two languages during childhood, by virtue of exposure to two rich language systems, can provide an intensified training ground for the development of linguistic and cognitive skills as well as enhance the sensory processing upon which these skills rely. If so, then even under conditions of socioeconomic impoverishment, bilinguals are predicted to demonstrate gains on certain linguistic and cognitive abilities as well as enhanced sensory processing relative to their monolingual peers. Alternatively, the linguistic under-stimulation associated with low SES, coupled with the splitting of that linguistic experience across two languages, could lead to more deleterious linguistic and cognitive outcomes and weakened sensory function for bilingual children from low-SES backgrounds relative to their low-SES monolingual peers.

To adjudicate between these two potential outcomes, the current study measured the consistency of millisecond-level, subcortical sound processing, a basic neural response property associated with language and cognitive skills (Centanni, Booker, Sloan, Chen, Maher *et al.*, 2013; Hornickel & Kraus, 2013) shown to be weaker in low-SES children (Skoe, Krizman & Kraus, 2013) and stronger in bilinguals (Krizman, Skoe, Marian & Kraus, 2014). We also examined linguistic and cognitive abilities that are sensitive to bilingualism and SES (Bialystok, Majumder & Martin, 2003; Bowey, 1995; Calvo & Bialystok, 2014; Campbell & Sais, 1995; Carlson & Meltzoff, 2008; Skoe *et al.*, 2013). Specifically, assessments included sight-word reading, phonemic decoding, and executive control, the ability to selectively attend to a target stimulus and ignore distracters. Adolescents who differed in socioeconomic standing, as indexed by maternal education, and language experience (i.e. English monolingual or Spanish-English bilingual), were compared on these various measures. An adolescent population was chosen because, while previous studies have shed light on the relatively immediate effects of SES and bilingualism on neural and cognitive function in young children (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; de Abreu *et al.*, 2012), little is known about how the accrual of both experiences throughout development shapes these functions during adolescence. Furthermore, extending the investigation of experience-dependent plasticity into this developmental period is important not only because the accrual of experience in adolescence is understudied, but also because adolescence is a time when the neural architecture underlying sensory and cognitive processes is still developmentally in flux. As a consequence of this extended developmental neuroplasticity, the nervous system continues to be influenced by ongoing linguistic experiences both in the immediate and the long term (Krizman, Tierney, Fitzroy, Skoe, Amar *et al.*, 2015b; Paus, 2005; Skoe, Krizman, Anderson & Kraus, 2015; Spear, 2000), further motivating our decision to focus on adolescence.

Methods

Participants

Sixty-two high school freshmen (M = 14.6 years, SD = 0.4 years, 32 female) attending three inner-city, public schools in Chicago, Illinois participated in this study. English monolinguals (M = 14.5 years, SD = 0.3 years; n = 32; 55% female) and Spanish-English bilinguals (M = 14.7 years, SD = 0.4 years; n = 30; 45% female) were recruited to participate. Inclusionary criteria were an IQ > 80 on a standard scale (Wechsler Abbreviated Scale of Intelligence, administered the same day as the other language and cognitive tests; Wechsler, 1999), air conduction thresholds of <20 dB hearing level (HL) for octaves from 125 to 8000 Hz, click-evoked auditory brainstem response latencies within lab-internal normal limits (5.41–5.97 ms, for a rarefacting click presented to the right ear at 80 dB sound pressure level (SPL) at a rate of 31/s), and no external diagnosis of an attention disorder (ADHD or ADD) according to parental report.

The Language Experience and Proficiency Questionnaire (LEAP-Q) (Marian, Blumenfeld & Kaushanskaya, 2007) and a parental report of the child's language abilities were used to measure language proficiency, as parental and self-reports have previously been found to be a reliable measure of second language experience (Bedore, Peña, Joyner & Macken, 2011; Gutierrez-Clellen & Kreiter, 2003). All participants and their parents reported high English proficiency (≥7 out of 10 on English speaking and understanding proficiency). Spanish-English bilinguals and their parents also reported high Spanish proficiency (≥7 out of 10 on Spanish speaking and understanding proficiency). The monolingual and bilingual participants did not differ on their self-rated English proficiency ($F(1, 57) = 1.246$, $p = .269$). The parent and the bilingual child indicated that the child learned both languages early (English age of acquisition: M = 3 years, SD = 1.8 years; Spanish: M = 2.1 years, SD = 1.7 years). Bilingual participants reported daily exposure to both English (61%) and Spanish (39%), and 55% of the bilinguals identified Spanish as their native language.

Monolingual and bilingual participants were subdivided into low- and high-SES groups based on a parental report of the highest education level of the mother. Although SES is a complex aggregation of measures, including parental education, parental occupation, family income, and social status (Duncan & Magnuson, 2012), one of the strongest predictors of SES in children is the educational level attained by the mother (Hoff, 2013). For the monolingual participants, 48.4% (n = 15) reported a maternal education of high school (n = 13) or less (n = 2) and 51.6% (n = 16) reported a maternal education of some college (n = 12) or higher (n = 4). Of the bilingual participants, 58.6% (n = 17) reported maternal education of high school (n = 12) or less (n = 5) and 41.4% (n = 12) reported a maternal education level of some college (n = 8) or higher (n = 4). Two participants (one monolingual, one bilingual) were excluded from analyses because maternal education and parental ratings of language proficiency were not reported.

Electrophysiological recording

Stimulus and recording

Auditory brainstem responses were recorded to the stimulus 'da', a dynamic, six-formant, 170 ms sound synthesized at a 20 kHz sampling rate using a Klatt-based formant synthesizer (Klatt, 1980). A noise burst comprises the first 5 ms of the stimulus for the initial unvoiced portion of the stop consonant. The 50 ms formant transition representing the consonant includes a steady fundamental frequency (F0, 100 Hz), a linearly rising first formant (F1; 400–720 Hz), a linearly falling F2 (1700–1240 Hz), a linearly falling F3 (2580–2500 Hz) and a constant F4 (3300 Hz), F5 (3750 Hz), and F6 (4900 Hz). The steady-state region (60 to 180 ms) corresponding to the vowel contains a constant F0 (100 Hz), F1 (720 Hz), F2 (1240 Hz), F3 (2500 Hz), F4 (3300 Hz), F5 (3750 Hz), and F6 (4900 Hz). This stimulus was chosen because it is a consonant-vowel pair that is common across many languages, including English and Spanish. The stimulus was not designed to contain features that would associate it with any language, but rather to contain the minimal features necessary to enable it to be perceived as a 'da' (see Skoe & Kraus, 2010, for additional information).

This sound was presented through an insert earphone in alternating polarity to the right ear (80 dB SPL, 3.98/s; ER-3A, Etymotic Research) using the stimulus presentation software NeuroScan Stim2 (Sound module, Compumedics). Brainstem electrophysiological response potentials were recorded with Ag/Ag-Cl electrodes applied in an ipsilateral, vertical montage (Cz-to-right earlobe and forehead as ground) using NeuroScan Acquire4 at a sampling rate of 20 kHz. Brainstem responses are relatively insensitive to subject state and can demonstrate inter-subject, experience-dependent differences even when recorded on sleeping (Krishnan, Xu, Gandour & Cariani, 2005) or otherwise-engaged participants (Hornickel & Kraus, 2013). Therefore, responses were passively collected while the participant sat in a comfortable reclining chair within an electrically shielded, sound-attenuated booth and watched a movie of his or her choice. The left ear remained unoccluded so that the participant could hear the movie soundtrack played at an intensity that did not mask the stimulus (<40 dB SPL).

Data averaging

Electrophysiological responses were off-line processed using Neuroscan Edit. First, responses were bandpass filtered from 70 to 2000 Hz (12 dB/octave, zero phase-shift), a frequency range that captures the phase-locking limits of the putative generator of this evoked response (i.e. the inferior colliculus) (Chandrasekaran & Kraus, 2010; Liu, Palmer & Wallace, 2006). Responses were then averaged over a −40 to 190 ms window (with 0 ms corresponding to the onset of the stimulus) and baseline corrected to the average pre-stimulus level. Responses exceeding ±35 μV were excluded from the average (i.e. artifact rejected). The final response comprised 6000 artifact-free sweeps, from which two averages were created: an average of the first 3000 responses and an average of the last 3000 responses.

Neural consistency

Evoked responses measure time-locked, synchronized population activity in response to an external stimulus (de Haan & Thomas, 2002; Hall, 2007); and, because evoked brainstem responses are temporally precise over a broad range of frequencies, they resemble the evoking stimulus (Figure 1a; Galbraith, Amaya, de Rivera, Donan, Duong *et al*., 2004; Skoe & Kraus, 2010). The heightened temporal precision of the brainstem in response to sound makes the trial-to-trial consistency of the evoked response a valuable measure (Tierney & Kraus, 2013). Indeed, how consistently the brain responds to the same stimulus over the duration of the recording session has previously been found to be experience dependent, both in terms of SES, as indexed by maternal education, and experience with a second language (Krizman *et al*., 2014; Skoe & Kraus, 2013; Skoe *et al*., 2013). Given that SES previously has been found to pervasively affect subcortical response consistency and bilingualism has been found to selectively bolster consistency in response to the steady-state vowel (Krizman *et al*., 2014; Krizman, Slater, Skoe, Marian & Kraus, 2015a; Skoe *et al*., 2013), we expected that SES would influence the response to the consonant, and aimed to observe the combined effects of SES and bilingualism on vowel response consistency in this study.

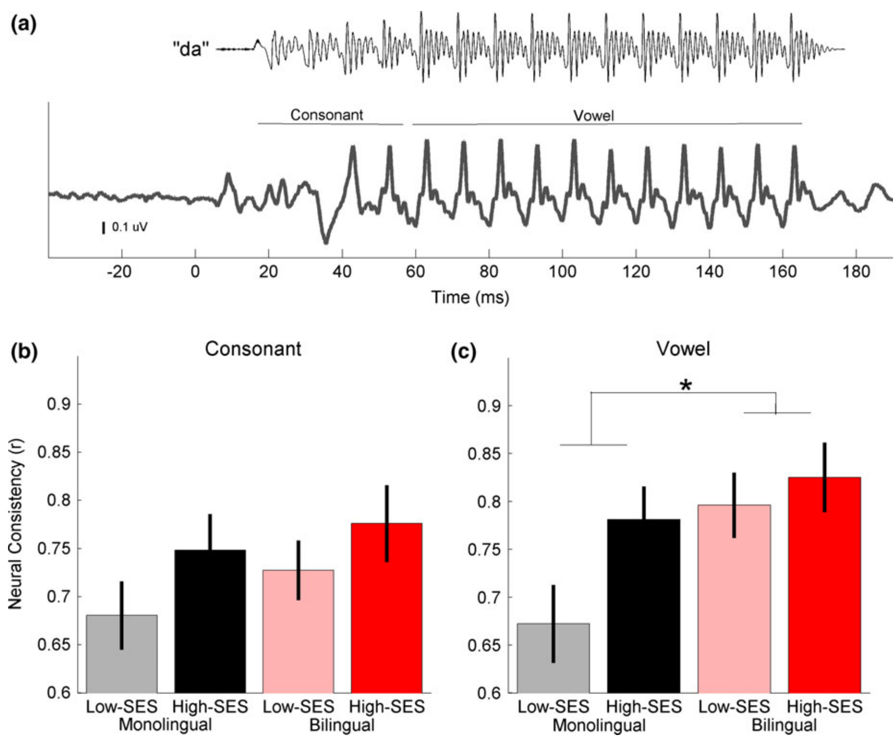

Figure 1 *Influence of socioeconomic status and second language experience on the consistency of the neural response. (a) Grand average response across all participants to the speech sound 'da' (above in gray). Lines signify the regions of the response that correspond to the consonant (5–60 ms) and vowel (60–180 ms) of the stimulus. (b) In response to the consonant, high socioeconomic standing corresponded with more stable responses. (c) In response to the vowel, both higher socioeconomic status and second language experience corresponded with greater stability of the evoked response.*

Therefore, neural consistency, measured over the response to the consonant (5–60 ms) and the response to the vowel (60–180 ms), was analyzed to determine the combined effects of language experience and SES within an individual. The consistency measure was calculated by correlating an average of the first 3000 trials to an average of the last 3000 trials (Hornickel & Kraus, 2013). The more consistently the brainstem responds to 'da' the more similar the two averages will be, and thus the higher their correlation (i.e. r) value (Tierney & Kraus, 2013; Krizman *et al.*, 2014), such that an r-value of 0 would indicate very low neural consistency and an r-value of 1 would indicate perfect neural consistency. To place the data on a normal distribution prior to running statistical analyses, r-values were Fisher z-transformed; however, for ease of visual comparison, figures show the original r-values.

Behavioral Testing

Executive Control (Full-scale response control)

Executive control was assessed with the Integrated Visual and Auditory Continuous Performance Test (IVA+Plus, www.braintrain.com, Richmond, VA), a 20-minute test in which 1s and 2s are presented pseudo-randomly on a computer screen or through headphones. The participant is to click the mouse whenever a 1, but not a 2, is seen or heard. This test was administered in English using headphones and a laptop computer placed 60 cm from the subject. IVA+Plus testing occurred separately from the electrophysiological testing, in some cases occurring on different test days. IVA+Plus performance was converted to age-normed standard scores and participants were compared on the 'Full-Scale Response Control' composite measure. This is a measure of how much an individual's performance changes when task demands change (i.e. when there are few distractors vs. when there are many distractors), providing a domain-general assessment of executive control across both auditory and visual modalities. A higher score indicates that the participant's performance (i.e. correctly responding to a 1 or not responding to a 2) is more consistent over the changing task demands.

Test of Word Reading Efficiency (TOWRE)

The TOWRE (Pearson, www.pearsonclinical.com) is a measure of phonemically regular non-word and real-word reading ability in a timed format. For both the phonemic decoding (i.e. non-word) and sight-word (i.e. real-word) reading tests, the participant is given 45 seconds to accurately pronounce as many items as possible in a list of real-words, and separately non-words. This test was administered to the participant in English and the non-words were based on English phonemes and pronunciation. Performance is age-normed and scaled to a mean of 100 $\pm$ 15 standard deviation for both the phonemic decoding and sight-word reading tests.

Statistical analyses

For the neural measures, a 2 (language group: monolingual, bilingual) $\times$ 2 (SES: low, high) analysis of variance (ANOVA) was run. To account for the influence of IQ on reading and executive control (Kuppen, Huss, Fosker, Fegan & Goswami, 2011; Schlaggar & McCandliss, 2007), a 2 (language group: monolingual, bilingual) $\times$ 2 (SES: low, high) analysis of variance co-varying for IQ (ANCOVA) was run on the behavioral measures. Given that the study was designed to assess how the four different experiences (i.e. low-SES monolingual, low-SES bilingual, high-SES monolingual, and high-SES bilingual) interact, Bonferroni-corrected planned t-tests were performed in addition to the 2 $\times$ 2 ANOVA analyses to further explore the influences of language experience and SES in adolescence. However, we limit our interpretation to only the effects that are justified by the ANOVA.

Results

Both high socioeconomic standing and bilingual experience bolstered the consistency of the neural response to sound. In addition, regardless of socioeconomic standing, bilingual adolescents outperformed monolingual adolescents on executive control and phonemic decoding tasks.

Neural response consistency

Neural consistency, measured in the evoked response to the syllable 'da', was affected by both language experience and socioeconomic standing (Figure 1). In the response to the vowel, there was a main effect of both language group ($F(1, 57) = 6.58$, $p = .013$, $\eta_p^2 = 0.105$) and socioeconomic standing ($F(1, 57) = 4.84$, $p = .032$, $\eta_p^2 = 0.079$), but no interaction between these two variables ($F(1, 57) = 1.43$, $p = .238$, $\eta_p^2 = 0.025$). Bonferroni-corrected planned comparisons showed that the low-SES monolingual response showed less stable neural responses than both the high-SES bilinguals ($p = .013$) and the low-SES bilinguals ($p = .046$). The low-SES monolingual group did not differ from the high-SES monolinguals ($p = .102$). The low-SES bilingual, high-

SES bilingual, and high-SES monolingual groups did not significantly differ (ps > .250).

In response to the consonant, there was a main effect of socioeconomic status ($F(1, 57) = 4.38$, $p = .041$, $\eta_p^2 = 0.073$), but there was neither an effect of language experience ($F(1, 57) = 1.13$, $p = .293$, $\eta_p^2 = 0.02$) nor an interaction of these two measures ($F(1, 57) = 0.24$, $p = .624$, $\eta_p^2 = 0.004$). The planned comparisons did not reach significance ($p \geq .230$).

Executive control: full-scale response control

On the measure of executive control, bilinguals, independent of socioeconomic standing, outperformed monolinguals, as evidenced by a main effect of language group ($F(1, 56) = 12.02$, $p = .001$, $\eta_p^2 = 0.185$; Figure 2). There was not a main effect of socioeconomic standing ($F(1, 56) = 0.12$, $p = .731$, $\eta_p^2 = 0.002$) nor an interaction between language experience and socioeconomic status ($F(1, 56) = 0.44$, $p = .508$, $\eta_p^2 = 0.008$). Bonferroni-corrected planned *t*-test comparisons across the four groups indicated that the low-SES bilingual participants outperformed the low-SES monolingual participants ($p = .049$) while the low-SES bilinguals and both high-SES groups performed similarly (ps > .250).

Language skills: phonemic decoding and sight word reading

To investigate the effects of bilingual experience and socioeconomic standing on language skills, groups were compared on phonemic decoding and word reading abilities. In regard to phonemic decoding ability, there was a main effect of bilingualism ($F(1, 56) = 4.45$, $p = .040$, $\eta_p^2 = 0.077$), with bilinguals outperforming monolinguals, while the effect of socioeconomic standing ($F(1, 56) = 0.09$, $p = .766$, $\eta_p^2 = 0.002$) and the interaction of bilingualism and SES ($F(1, 56) = 0.41$ $p = .523$, $\eta_p^2 = 0.008$; Figure 2) were not significant. For word reading ability, there was a trending main effect of socioeconomic standing ($F(1, 56) = 2.91$, $p = .094$, $\eta_p^2 = 0.052$), while the effect of bilingualism ($F(1, 56) = 0.07$, $p = .793$, $\eta_p^2 = 0.001$) and the interaction of bilingualism and SES ($F(1, 56) = 1.89$, $p = .175$, $\eta_p^2 = 0.034$; Figure 2) were not significant. For both phonemic decoding and real-word reading, planned comparisons between the four groups did not reach significance (all ps > .250).

Discussion

Bilingualism and socioeconomic standing influence neural processes fundamental to linguistic and cognitive function (Kraus & Nicol, 2014). We build on previous findings of greater neural consistency in bilinguals (Krizman *et al.*, 2014) by showing that this neural signature of bilingualism can develop regardless of the socioeconomic status of the child. Moreover, we find that bilinguals, irrespective of SES, demonstrate greater executive control and phonemic decoding abilities than their monolingual peers. These results are in line with previous findings of an advantage for executive control in bilinguals from low-SES backgrounds (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008; de Abreu *et al.*, 2012) and enhanced phonological skills in bilin-

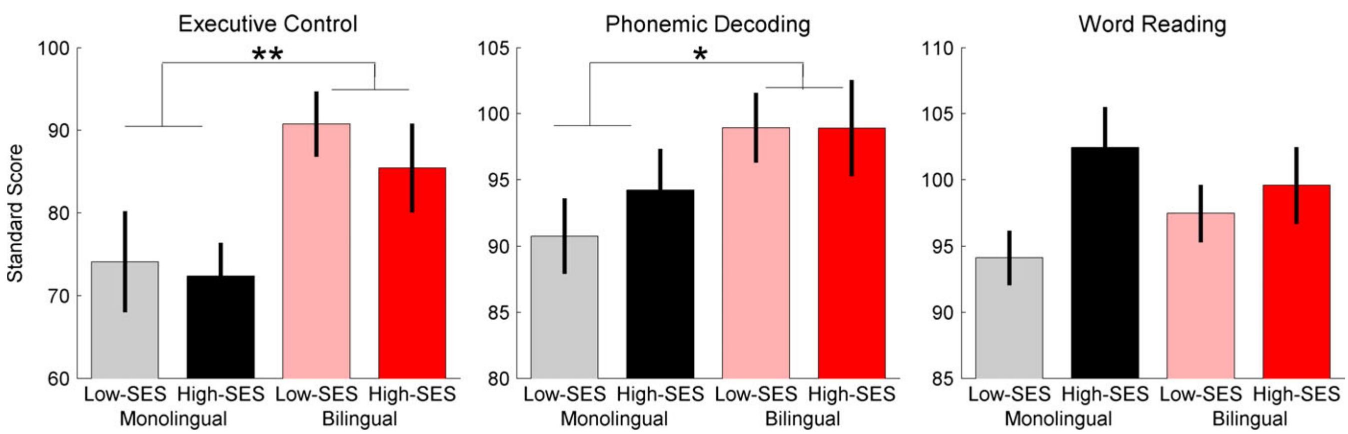

Figure 2 *Influence of socioeconomic status and second language experience on measures of executive control and reading, covarying for IQ. The bilingual participants demonstrated greater executive control and phonemic decoding (i.e. non-word reading) abilities than the monolinguals. Real-word reading abilities were trending with socioeconomic status, where higher SES individuals had higher word reading scores.*

gual children (Bialystok *et al*., 2003; Campbell & Sais, 1995). Consistent with previous results using a different evoking stimulus (Skoe *et al*., 2013), we also find that low SES adversely influences neural response consistency. Taken together, these findings support the argument that bilingualism provides an enriched linguistic environment that can facilitate enhancements in sensory and cognitive function (Kraus & White-Schwoch, 2015) in children from both low- and high-SES families.

Socioeconomic status is determined by an aggregation of social, political, educational, and financial factors (Duncan & Magnuson, 2012; Hollingshead, 1975). However, we, like others, used maternal education as a proxy for SES in children (Noble, Wolmetz, Ochs, Farah & McCandliss, 2006; Stevens *et al*., 2009). We chose this metric because maternal education is the aspect of SES that most significantly and pervasively influences a child's language skills (Hoff, 2003, 2013; Huttenlocher, Waterfall, Vasilyeva, Vevea & Hedges, 2010; Pan, Rowe, Singer & Snow, 2005). There are disparities between low- and high-SES youth in vocabulary size (Calvo & Bialystok, 2014; Hart & Risley, 1995), phonological awareness (Bowey, 1995; Noble *et al*., 2006), and grammatical knowledge (Dollaghan, Campbell, Paradise, Feldman, Janosky *et al*., 1999; Hoff, 2003; Huttenlocher *et al*., 2010) and linguistic impoverishment has been implicated as a causal link between socioeconomic impoverishment and poorer executive function (Noble *et al*., 2007; Raizada & Kishiyama, 2010). Our findings provide further support for the adverse impact of auditory-based linguistic impoverishment on language skills and executive functions within an adolescent population and suggest that it does so by adversely influencing the consistency of the sensory processing upon which these cognitive abilities rely. It should be noted that all adolescents in this study came from inner-city Chicago high schools serving predominately low-income communities. Thus the impact of maternal education is particularly striking in this context.

Consistency of the neural response increases from infancy through adolescence (Skoe *et al*., 2015) and this increase in neural stability has been shown to be experience dependent, such that auditory enrichment during this period can promote greater consistency in the neural response (Hornickel, Zecker, Bradlow & Kraus, 2012; Skoe & Kraus, 2013). From this perspective, then, bilingualism and higher socioeconomic status provide enriching auditory environments that can promote enhancements in sensory encoding by enabling more stable neural processing of sound. Given the known differences in linguistic experience between children from low- and high-SES families (Hart & Risley, 1995) and between bilinguals and monolinguals (Bialystok, 2011; de Abreu *et al*., 2012), we suggest that language experience likely underlies the boost to neural consistency. Moreover, as language-related plasticity of the auditory system unfolds during development, enhancements occur in both sensory processing (Jeng, Hu, Dickman, Montgomery-Reagan, Tong *et al*., 2011; Krishnan *et al*., 2005; Kuhl & Rivera-Gaxiola, 2008) and cognitive abilities (Calvo & Bialystok, 2014; Carlson & Meltzoff, 2008). Gradients in cognitive function dovetail with gradients in neural response consistency (Hornickel *et al*., 2012; Krizman *et al*., 2014), suggesting that the degree of stability of the neural response reflects the extent of coupling between sensory and cognitive systems. It has been proposed that a stable neural response to sound provides a platform upon which cognitive skills and sensory processing can mutually influence one another (Kraus & White-Schwoch, 2015), that enrichment can strengthen this connection (Kraus & Chandrasekaran, 2010), and that the breakdown in this coupling may underlie certain types of auditory processing disorders (Skoe *et al*., 2013; Hornickel and Kraus, 2013). Interestingly, however, although both bilingualism and SES can act as a form of linguistic enrichment that boosts cognitive and sensory function, the effects of bilingualism and SES manifested in somewhat different forms in our study: bilingualism bolstered phonemic decoding of non-words while SES influenced real-word reading; moreover, while both high SES and bilingualism were associated with greater consistency in the encoding of the longer, steady-state vowel, only higher SES levels translated to greater consistency in processing the faster-changing consonant.

From our findings, we propose that regardless of socioeconomic standing, bilingualism is a source of linguistic enrichment that engenders neural enhancements and bolsters cognitive and sensory processing during adolescence (Krizman *et al*., 2012; Krizman *et al*., 2014). In addition to the current results, there is prior evidence to support an enriching role of bilingualism. Although bilinguals tend to have a smaller within-language vocabulary than monolinguals, bilinguals often show a larger vocabulary than monolinguals when collapsing across the two languages. (Bialystok, 2009). Moreover, while a monolingual's phonological space is parceled up by a discrete number of phonemes of a single language, a bilingual must further subdivide that same space to accommodate the phonemes of two languages (Albareda-Castellot, Pons & Sebastián-Gallés, 2011; Burns, Yoshida, Hill & Werker, 2007; Flege, Schirru & MacKay, 2003; Imai, Walley & Flege, 2005). This need to acquire a larger number of acoustically similar phonemes, and have more fluid phonological processing, may contribute to both the enhanced phonemic decoding skills and heightened response consistency observed in both the low- and high-SES bilinguals. In addition to greater vocabulary size and phonemic decoding abilities, bilingualism also confers enhancements on certain executive functions, even under conditions of socioeconomic impoverishment. Support for this comes not only from the current study but other studies showing that low-SES bilinguals outperform low-SES monolinguals (Calvo & Bialystok, 2014; de Abreu *et al.*, 2012) and perhaps high-SES monolinguals (Carlson & Meltzoff, 2008) on measures of executive control. Given that executive control, phonemic decoding, and neural response consistency are considered important for both language development and academic success, these results support the idea that bilingualism is a source of enrichment that can benefit cognitive abilities and sensory processing and so should be encouraged for everyone irrespective of SES.

Immigrant families, especially in the United States, are more highly represented in low- than high- socioeconomic strata (Fennelly, 2005; Hernandez, 2004). Thus, many low-SES children come from homes where the majority (i.e. official) language is not used and so are not routinely exposed to that language until the start of school. Unsurprisingly, when assessed in the majority language at the onset of schooling, these heritage-language speakers are behind on measures of academic readiness (Hoff, 2013). Over the course of their education, growth in the heritage language wanes in favor of the majority language (Lynch, 2003; Pearson, 2007). This language switch can impede mastery of the first language as well as scholastic achievement (Hoff, 2013). In an effort to circumvent this problem, some schools offer bilingual education, in which the child receives instruction in both the heritage and the majority language. In the US, these programs have varied in success and some school districts have abandoned them as a resource for their students to prevent declines in the school's academic rankings (Lynch, 2003). The early lag in academic readiness at the outset of schooling, coupled with its adverse impact on the school's rankings, has negatively fueled the debate on bilingualism in the United States. However, few studies have examined the long-term benefits of bilingualism in school-age children. Our study fills this gap by focusing on an adolescent population. Our results suggest that when students are given the opportunity to master two languages, this can lead to subsequent gains in neural processing, phonological abilities, and executive control, all of which contribute to academic success. Thus, while bilingualism may originally translate to a lag in academic readiness at the start of a child's education, our findings suggest that the accrual of bilingual experience throughout development confers unique advantages that are observable in both low- and high-SES bilingual adolescents.

Conclusions

This study extends our knowledge of the influence of language experience on the developing brain by investigating how maternal education and second language experience, shape the neural processing of sound, executive control, and phonological processing during adolescence, an understudied yet important developmental period. We find that lower maternal education is associated with negative effects on cognitive and auditory neural function, and we propose that it is likely through the linguistic deprivation associated with lower maternal education. In contrast, we find that bilingualism can confer advantages on measures that are impoverished in low-SES youth; and suggest that it does so because bilingualism provides an enriched linguistic environment for children. Results from this study support the idea that second language experience should be fostered in children from both low- and high-SES.

Maternal education was the aspect of socioeconomic status on which these adolescents were divided; however, other aspects of socioeconomic status may also contribute to the overall cognitive, linguistic, and sensory function of an individual. Future studies can examine groups who differ on additional factors that make up SES, such as financial or material wealth. Moreover, while the current study focused on a period when auditory and cognitive systems are still developing, future studies should also investigate the contributions of SES and bilingual experience on populations where these systems are stable, such as in young adulthood, or perhaps more importantly, at a point when the auditory and cognitive systems are in decline, as is seen in the aging population. Given that poorer auditory and cognitive function, often associated with increasing age, have negative consequences on real-world communication abilities, it is important to understand how SES and bilingualism can mitigate decline of these functions in an aging population.

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