Published in final edited form as:
J Speech Lang Hear Res. 2011 June ; 54(3): 821–835. doi:10.1044/1092-4388(2010/09-0018).

Production of lexical stress in non-native speakers of American English: Kinematic correlates of stress and transfer

Rahul Chakraborty and
Texas State University - San Marcos

Lisa Goffman
Purdue University

Abstract

Purpose—To assess the influence of L2 proficiency on production characteristics of rhythmic sequences in L1 (Bengali) and L2 (English), with emphasis on linguistic transfer. One goal was to examine, using kinematic evidence, how L2- proficiency influences the production of iambic and trochaic words, focusing on temporal and spatial aspects of prosody. A second goal was to assess whether prosodic structure influences judgment of foreign accent.

Method—Twenty Bengali-English bilinguals, 10 with low proficiency and 10 with high proficiency in English, and 10 monolingual English speakers participated. Lip and jaw movements were recorded while the bilinguals produced Bengali and English words embedded in sentences. Lower lip movement amplitude and duration were measured in trochaic and iambic words. Six native English listeners judged the nativeness of the bilingual speakers.

Results—Evidence of L1 to L2 transfer was observed through duration but not amplitude cues. More proficient L2 speakers varied duration to mark iambic stress. Perceptually, the high proficiency group received relatively higher native-like accent ratings. Trochees were judged as more native than iambs.

Interpretation—Even in the face of L1-L2 lexical stress transfer, non-native speakers demonstrated knowledge of prosodic contrasts. Movement duration appears to be more amenable to modifications than amplitude.

Introduction

Production of Lexical Stress and Linguistic Transfer

Stress is defined as the perceived prominence of a syllable in a multisyllabic word (e.g., Archibald, 1993; Major 2001). Perceptually, stressed syllables are expected to be comparatively longer in duration, higher in pitch, and perhaps louder than unstressed syllables (e.g., Archibald 1992; Hayes, 1995; Major, 2001). Numerous investigators have studied movement parameters associated with different aspects of stress (e.g., Beckman & Edwards, 1994; Cho, 2002; de Jong 1995; Fowler, 1995; Mooshammer & Fuchs, 2002; Munhall, Ostry & Parush, 1985). Although several kinematic correlates of stress have been identified, in common across these studies is that amplitude and duration are usually markers of stress. These temporal and spatial movement variables apply well to the lexical stress contrasts studied here.

Contact: Rahul Chakraborty, Ph.D. Department of Communication Disorders, 601 University Drive, Texas State University, San Marcos, Texas 78666, Phone: 512 245 6577, rc39@txstate.edu, Fax: 512 245 2029.

Stressed syllables are usually produced with relatively larger amplitude and longer duration movements compared with unstressed syllables (e.g., Cho, 2002; Goffman & Malin, 1999; Mooshammer & Fuchs, 2002). Kinematic correlates of lexical stress are identified based on their relative differences, with no fixed values that can be attributed to stressed or unstressed syllables (de Jong, 1995; Engstrand, 1988; Summers, 1982). In this paper, we evaluate the temporal and spatial articulatory cues associated with stress in speakers as they produce sentences in their first and their second languages. First, we attempted to understand kinematic behaviors of two groups of bilinguals with varying degrees of second language (L2) proficiency. Second, linguistic transfer was explored through the examination of kinematic variations of language specific prosodic contrasts.

L1-L2 Transfer—In bilingual speakers, the two languages are known to influence each other and components from one language are frequently transferred to another (e.g., Gass, 1996; Jarvis & Oldin, 2000; Jones, 2005; Treffers-Daller & Mougeon, 2005). Linguistic transfer refers to the covert behavior in which knowledge of a native or other dominant language influences a second language (e.g., Archibald, 1995; Odlin, 1989; Weinreich, 1953). Transfer has been observed at various linguistic levels, including lexical, prosodic, syntactic, semantic, and phonological (e.g., Gass, 1996; Jarvis & Oldin, 2000; Jones, 2005; Major, 2001; Treffers-Daller & Mougeon, 2005; Weinreich, 1953). An inherent factor in such transfer phenomena is how similar or different the languages are with reference to the target linguistic construct, which is lexical stress in the present project. Although most studies of transfer have explored the influence of L1 on L2 (Archibald, 1992; 1993; 1995; Major, 2001; Odlin, 1989), depending upon the relative dominance of L1 and L2, the nature and direction of transfer might vary; influences may be bidirectional (Bernardini & Schlyter, 2004; Heredia & Altarriba, 2001; Pavlenko & Jarvis, 2002; Wolff & Ventura, 2003; Yeni-Komshian et al., 2000).

Usually, non-native elements emerge when L1 and L2 are different with reference to a target language subsystem or construct (e.g., Major, 2001; Wode, 1978). Archibald (1992; 1993) investigated native speakers of Polish and Hungarian acquiring English stress. In Polish, stress is predominantly fixed and is assigned to the penultimate syllable. Polish speakers frequently produce penultimate stress in English words that have antepenultimate stress. Hungarian is another language where stress is predominantly fixed and primary stress is assigned to the initial syllable of a word. In English polysyllabic words, native Hungarian speakers usually stress the initial syllable. Similarly, even though to our knowledge no one has explored how Bengali speakers would assign lexical stress to English words, in Bengali it is thought to be obligatory to assign stress only to the initial syllable. A primary objective of the present study is to assess how temporal and spatial cues related to the production of stress are implemented in a trochaic language (Bengali) and are transferred to a second language with different stress rules (English).

Production and Perception of Foreign Accent

Multiple factors (e.g., age of L2 learning and amount of L1 and L2 use) are known to influence non-native speakers' production of L2 targets and consequently native speakers' judgment of foreign accent. However, based on native speakers' judgment of non-native speakers' production of L2, only the age of L2 learning (e.g., Asher & Garcia, 1969; Flege & Fletcher, 1992; Flege, Munro & MacKay, 1995; Flege, Yeni-Komshian & Liu, 1999; Long, 1990; Moyer, 1999; Patkowski, 1990) and the amount of L1 use (e.g., Flege, Frieda & Nowaza, 1997; Guion, Flege & Loftin, 2000a;) had significant and independent effects on L2 production accuracy (Piske et al., 2001). In general, it is reported that the presence of a detectable non-native accent is evidence of L1 influence on L2 and age related changes in L2 accent depend on the nature and extent of interaction between L1 and L2 (see Piske, et

NIH-PA Author Manuscript

NIH-PA Author Manuscript

al., 2001; Weinreich, 1953). The more developed and elaborated the L1 system is at the onset of L2 exposure, the more influence L1 will exert on the L2 system. As a consequence of L1's influence on L2, speakers will sound non-native. Overall, age could be considered as an index of the developmental status of the L1 system and age-related changes in the degree of non-native accent are related to the nature and the extent of interaction between the L1 and L2 systems (e.g., Birdsong, 1999; Lenneberg, 1967; Penfield & Roberts, 1959; Seliger, 1978). In this project we explore the influence of language proficiency, defined as the age of academic immersion in English combined with performance on a test of English grammar, on stress transfer in adult Bengali-English bilinguals.

English and Bengali are typologically different in lexical stress. English is a language in which lexical stress can be movable (e.g., PERmit is a strong-weak sequence associated with a noun, whereas perMIT is a weak-strong sequence associated with a verb; McCully, 2002). However, trochaic (i.e., strong-weak) nouns are far more frequent than iambic (i.e., weak-strong) nouns. Overall, in English, even though iambic nouns occur, statistically, trochaic nouns predominate (Coltheart, 1981).

Based on the little information that has been documented about Bengali stress patterns, it is known that, regardless of grammatical class, an inviolable rule is that the first syllable of a word has to be stressed (Chatterji, 1921; Hayes & Lahiri, 1991; Klaiman, 1987). Thus, Bengali does not have words with an iambic rhythm. However, to our knowledge, there has been little work detailing the stress patterns of Bengali, and none characterizing the articulatory correlates of the Bengali stress system, either in adults or in children.

Aspects of Movement Sensitive to Language Experience

Every language requires distinct speech production strategies to execute language specific parameters. It is expected that these articulatory strategies differ across languages and that second language learners must execute complex and precisely tuned motor control strategies based on language specific requirements to approximate native-like pronunciation (e.g., Klien, 1995; Scovel, 1988). Age-related reductions in movement flexibility (e.g., Smith & Goffman, 1998; Smith & Zelaznik, 2004) may relate to reported difficulties in modifying the sensori-motor programs used for producing native-like accent (e.g.,; Klien, 1995). These findings suggest that speech motor plasticity is reduced in adults, and such changes would also influence the capacity to apply new speech motor patterns to the production of linguistic types, such as trochaic and iambic stress targets.

Production of L2 has seldom been examined through direct measures of articulatory movement (except Chakraborty, Goffman, & Smith, 2008; Flege, 1988b; Nissen, Dromey & Wheeler, 2007; Zsiga, 2003). Flege (1988b) reported that native English speaking adults used greater displacement and peak velocity in producing word-final English /p/ and /b/ than native English speaking children who, in turn, used greater displacement and peak velocity than adult native speakers of a language (Mandarin Chinese) that does not include word final stops. Velocity and displacement cues are relevant to the production of differentiated stop consonants (Flege, 1988b). Zsiga (2003), on the other hand, compared patterns of consonant-to-consonant timing at word boundaries in English and Russian and reported evidence of linguistic transfer. Chakraborty et al. (2008) examined the variability of patterning of movement trajectories associated with sentences produced in L1 (Bengali) and L2 (English) and compared speakers with high proficiency and low proficiency in L2. Their findings suggest that speech motor control systems of adult bilinguals show a high degree of consistency and are not influenced by their L2 proficiency. For the production of lexical stress, spatial and temporal cues provide an approach to assess transfer.

In the present study we use direct recordings of lip and jaw movements of bilingual speakers to understand how L1 and L2 stress patterns transfer. Assessment of the relative duration and amplitude of articulatory movements in stressed and unstressed syllables offers a means to explore the articulatory control of stress (e.g., Beckman & Edwards, 1994; Cho, 2002, de Jong, 1995; Goffman, Heisler, & Chakraborty, 2006; Goffman & Malin, 1999; Mooshammer & Fuchs, 2002). We only investigate one component of the articulatory complex, lip and jaw movement. Of course, other components of the articulatory complex, such as lip aperture, tongue movement and phonatory and respiratory drive, contribute to stress contrasts (Browman & Goldstein, 1992). However, amplitude and duration of lower lip movements serve as a major contributor to the production of the specific stimuli selected for this study. Kinematic analysis can reveal spatial and temporal characteristics of lexical stress in English and Bengali. Not only can the structure of lexical stress patterns be detailed for each language, but this analytic approach also has the potential to assess transfer.

In summary, kinematic analysis can be used to assess if highly or less proficient bilinguals producing L2 demonstrate transfer. Adults who are second language (L2) learners represent an important test-case of such language-motor interactions, because they are at an advanced level of motor and language learning in L1, but lack equivalent experience in L2. However, to our knowledge, very few investigators (Chakraborty, Goffman & Smith, 2008; Flege, 1988; Zsiga, 2003) have explored the nature of speech motor control in bilingual speakers.

Present Study and Hypotheses

In the present study we assess the influence of oral L2 proficiency on production characteristics of rhythmic sequences in L1 (Bengali) and L2 (English), with particular emphasis on linguistic transfer. We use kinematic analysis to evaluate whether monolingual and bilingual speakers of English include two distinct prosodic structures in their production of iambic and trochaic words, focusing on temporal and spatial aspects of prosody. We also assess whether prosodic structure influences judgment of foreign accent in second language learners. Our specific hypotheses are:

1. In English, highly proficient speakers of L2 (English) will show minimal transfer by producing small and short lower lip/jaw movements in iambs. Conversely, the less proficient L2 speakers will import the trochaic Bengali stress pattern in their production of the iambic target.

2. In Bengali (L1), low and high proficiency speakers are expected to produce only a single prosodic category, one that is trochaic. All target nouns are predicted to be produced with similar movement amplitude and duration across weak and strong syllables. Perceptually, more proficient speakers of English will be judged as more English native-like in their L2 accent and trochees as more native--like than iambs.

Method

Participants

Thirty participants were included in this study, including a group of 20 Bengali-English bilingual speakers (M=28.6 years, range 24 to 35 years) and 10 monolingual English speakers (M=22 years, range 20 to 24 years). Only speakers with no history of speech, language, reading, or neurological problems, as self-reported on a case history, were included. All participants passed a hearing screening at 20 dB at .5 kHz, 1 kHz, 2 kHz, 4 kHz and 6 kHz.

Standard Bengali was the first language of all the Bengali-English speakers. All of the bilinguals were born in West Bengal, India, where Bengali was the primary language of communication. Based on the age of academic immersion in English, of the 20 bilingual speakers, 10 (5 female) had a history of early exposure to English (from the primary school level), and the remaining 10 (5 female) had relatively late exposure to English (only after the college level). These two groups were classified as early exposed and late exposed groups. Critically, as described below, measures of English proficiency perfectly coincided with age of immersion. Both groups had lived in the US for similar periods of time, and thus had similar exposure to standard American English. The initial age of arrival in the USA (24 – 26 years) was similar across groups. Participants were either graduate students or post-doctoral fellows at Purdue University, located in the Midwestern region of the US.

To measure English language proficiency, all 20 bilingual participants and the 10 monolingual American English speakers were given the Speaking Grammar subtest of the *Test of Adolescent and Adult Language* (TOAL-3; Hammill, Brown, Larsen, & Wiederholt, 1994). The TOAL-3 has been previously used for the classification of nonnative adult speakers' English proficiency (Chakraborty, Goffman, & Smith, 2008; Guion, 2005). Because the TOAL-3 is not standardized on bilingual speakers only the raw scores are reported. Speaking grammar scores for the 10 monolingual native English speakers ranged from 19–27 (with a maximum possible score of 30), M=23, SD=2.58. For the 10 participants exposed to English early, the speaking grammar scores ranged from 15–26, M=21.4, SD=3.75. The 10 speakers in the late exposed group had speaking grammar scores ranging from 3–10, M=7, SD=2.75. A one-way ANOVA was performed. There was a significant group effect, $F(2, 27) = 82.42$, $p < .001$, $\eta_p^2 = .86$. Information about participants' chronological age, gender, age of arrival in the USA, scores on Speaking (Sp) Grammar Subtest and the languages they speak is presented in Table 1. Overall, the proficiency classification using the TOAL-3 coincided with age of exposure to English. That is, both L2 experience and proficiency overlapped across the two bilingual groups. Hence, the two proficiency groups were labeled as "early-high" and "late-low." One set of analyses considered global effects of language experience and proficiency, where bilinguals were compared with the monolingual speakers of English in the English language context. All 30 participants (10 monolinguals, 10 early and 10 late bilinguals) were included in those analyses. A second set of analyses addressed questions about the influence of L2 proficiency on L1. For this set, only the 10 early-high and the 10 late-low participants were compared in the Bengali language context.

Participants in the perceptual judgment analyses included six native English listeners. All six participants were graduate students in Speech-Language Pathology at Purdue University (Mean age = 23 years), were monolingual speakers of standard American English with minimal exposure to speakers of Indian English background, and had no history of hearing loss.

Stimuli

Participants produced four words embedded in language specific sentence frames. All of the sentence frames were comprised of five syllables. The phonetic content of these words were consistent with the typical lexical inventory of both languages and also were semantically similar across English and Bengali. An additional constraint, critical for tracking lip and jaw movement, was that the words included initial and medial labial consonants. It is important to note that, although semantically these words have been assimilated into the native inventory of Bengali and standard American English, etymologically their origins are still considered foreign. The trochaic words selected, marble ([marbl]; from Ancient Greek) and bible ([baIbl]; from Latin and Greek), were meaningful in both English and Bengali. The iambic words, also meaningful in both languages, were buffet ([bəfeI]; from French) and baboon ([bəbun]; from French). It should be mentioned that buffet and baboon, which are produced using an iambic stress pattern in English, are expected to shift to a trochaic pattern

NIH-PA Author Manuscript

NIH-PA Author Manuscript

in Bengali, since the iambic pattern is not permissible. These words were embedded into the sentence frame “I have said_____ before” in the English condition and “ami ______ bolechi” (which means, “I have said____ ”) in the Bengali condition.

Procedures and Data Recording

To elicit words, pictures and their corresponding written labels in the target language were shown individually on a computer monitor, which was positioned 6 feet anterior to the participant. No instruction or models pertaining to the target pronunciation or lexical stress pattern were offered to the participants so that they would produce their natural stress patterns for the target stimuli. Once the participants were oriented to the stimuli and had produced the target words in isolation, they were told that, every time they saw a picture on the computer screen, they needed to remember if they had said the corresponding name of the picture before. If they had said the name of a target picture, they were required to say, for example (in the English language condition), “I have said_______ before.” Otherwise, they would be cued to say “I have not said _______ before.” This routine elicited words in a consistent sentence frame. Initially filler words were used to teach the sentence frame. Four words for each language were used as fillers (i.e., dog, cat, car, and mouse in English and their Bengali equivalents). An additional 10 filler words were randomly distributed throughout the experimental session to elicit the phrase “I have not said ____ before” or its Bengali equivalent “ami ______ bolini.” No feedback was provided about the target words. However, feedback with filler words was offered if an incorrect sentence frame was produced. In this condition, the trochaic and iambic words were randomized. After collecting 15 fluent tokens of sentences containing each stimulus word, this condition was considered complete. A second experiment involving the production of novel words was included, but will not be reported on here.

Three types of data were collected, kinematic, video and acoustic. Kinematic data were obtained using a Northern Digital Optotrak 3020 camera system (Waterloo, Ontario), which records human movement in three dimensions. This system tracks movement by sensing the location of small (approximately 7 mm) infrared light emitting diodes (IREDS) and recording their positional changes (Smith et al., 2000). Eight IREDS were used. Four IREDS were attached to the upper lip, lower lip, forehead and jaw at midline using medical adhesive. The jaw IRED was attached at midline to a small, lightweight, ‘L’ shaped splint projected inferiorly under the chin (Smith et al., 2000). The remaining four IREDS were mounted to modified sports goggles. These four reference IREDS were used to compute the three dimensional axes for the head. Motions of the upper lip, lower lip and jaw were calculated, using this head coordinate system as a reference to correct for head motion artifact (Smith et al., 2000). Only the superior-inferior dimension of movement was analyzed, as this was the primary contributor for the speech sounds included in these stimuli (with the exception of the rounded vowel in the second syllable of “baboon”). The sampling rate for the kinematic data was 250 Hz. The acoustic signal was simultaneously digitized at 16 KHz by the Optotrak Data Acquisition Unit (ODAU). This signal provided an audio record that was synchronized to the movement data. The audio signal was used off-line to ensure that the kinematic records corresponded with the appropriate speech sample.

A separate video and DAT recorder were used to record the entire experimental session. This video recording was used off-line to code the fluent and error free tokens of the experimental stimuli. The DAT recordings were also used for the perceptual judgment analysis. Participants were seated on a stable chair 6 feet from the camera. The microphone for obtaining DAT recordings was mounted 16 inches from the speaker’s mouth.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Perceptual Judgment

The aim of the perceptual judgment portion of the experiment was to examine how native English speakers perceptually categorized the highly proficient and the less proficient speakers' productions of the English words. To address this issue, two samples of each target word were extracted from the English sentence using PRAAT acoustic software (Boersma & Weenink, 2009). Individual words were randomly selected for each speaker; 8 tokens (4 words X 2 samples of each) were selected and randomized across all 20 bilinguals. Tokens were delivered through earphones and each listener ranked the productions on a 9-point metathetic scale, where 9 represented 'very native' and 1 represented 'very non-native.' The listeners were given a short training to familiarize them with the interval scaling procedure. Listeners were instructed to judge the degree of nativeness of the speaker. They were not specifically asked to evaluate the stress pattern. Stimuli were presented one at a time and the order of presentation was fixed across all the participants.

We selected a 9-point metathetic scale instead of a prothetic scale because it has been reported that judgment of perceived degree of foreign accent is more appropriately reflected on a metathetic continuum (Southwood & Flege, 1999). Southwood and Flege (1999) compared a seven-point equal-appearing interval scale (metathetic scale) and direct magnitude estimation (DME; prothetic scale) to determine if accentedness was a prothetic or metathetic continuum and reported that accentedness is amenable to linear partitioning. However, they recommended use of a 9- or 11-point scale to measure perceived degree of foreign accent, to avoid the potential ceiling effects that might be associated with a 7-point scale.

Establishing Language Mode and Summary of Session Structure

For bilingual speakers, there were two language contexts, an L1 (Bengali) and an L2 (English) context. Only the English context was implemented for the monolingual English speakers. Initially, to establish the context of the targeted language and also to ensure that participants were comfortable speaking with IREDS, a 3 minute video clip was shown, and non-experimental reading and speaking tasks in the target language were completed. Participants first watched a language specific video clip reflecting the cultural aspects of the target language (e.g., a popular movie clip), and then read aloud a short paragraph in the target language (e.g., a review of a movie written in the target language), followed by answering a general question in that language (e.g., "what would you say about Bengali social lives to an American?" for the bilinguals and "what would you say about American social lives to a person from India?" for the monolingual English speakers).

Data were collected across two separate experimental sessions, each lasting approximately one hour and targeting only one language, either English or Bengali (order counterbalanced). A native speaker of the target language interacted with the participants. For example, if the target language for a session was Bengali, then a native Bengali speaker conducted the session. During the first session, participants completed the experimental task in one of the target languages, followed by the hearing screening and the Speaking Grammar subtest of the TOAL- 3. During the second session, participants completed the experimental task in the second language.

Analyses

Video coding—Two observers coded the videotapes to identify utterances that contained no disfluencies, segmental errors, unnatural pauses or extreme head movement. Only the first 10 consecutive tokens agreed upon by both coders were included for analysis.

Kinematic data collection—Kinematic signals from lower lip were imported with the accompanying speech acoustic signal into a signal processing program written for Matlab (Mathworks, 1993). Oscillatory motion of the lower lip/jaw complex has been found to be a critical parameter in conveying spatial and temporal correlates of stress (Goffman, 1999; Goffman & Malin, 1999). All kinematic signals were low-pass filtered (10 Hz cut-off) in forward and backward directions using a Butterworth filter. The three-point difference method was used to compute velocity.

Data extraction—To segment the words from their carrier phrases, continuous displacement and velocity signals from the lower lip marker were displayed. It should be noted that the signal from the lower lip marker is a resultant of combined lower lip and jaw movement. Since this combined signal is derived from the lower lip IRED only, this signal will be referred to as the lower lip signal. Waveforms corresponding to the target iambic and trochaic words were extracted from each continuous displacement file. Onsets and offsets of target words were selected visually, using the maximum displacement points that corresponded to the closure of the labial consonants (Goffman et al., 2006). For example, as shown in the top panel of Figure 1, the onset in “I have said buffet before” corresponds with the initial closure for the consonant “b” in “buffet” and the offset corresponds with the closure for “b” in “before.” Using a 25-point (100 ms) decision window, an algorithm automatically determined the location of the zero-crossing in the velocity profile that corresponded to the already selected onset or offset points associated with a target word. The onset and offset points were determined from the lower lip marker only, and these indices were then used to segment time-locked data from the upper lip and jaw signals. Because displacements and durations from movement associated with individual syllables were also analyzed, these sequences were also extracted, as illustrated in the bottom panel of Figure 1. In this case, the onset of the first syllable corresponds with the “b” in “buffet” and the offset with the “f.” The onset for the second syllable was also defined, in this example, as the closure for the “f” and the offset the closure for the “b” in “before.” Using these analyses, duration and amplitude measures corresponding to words and syllables were obtained. To ensure that the kinematic data segmented for analysis corresponded to the target speech sample, the onset and offset points were used to play back the speech acoustic signal from that time interval.

Measures of lexical stress and transfer—These analyses were designed to evaluate whether bilingual speakers were using differentiated movement modulation across weak and strong syllables, in both L1 (Bengali) and L2 (English) and whether, for high or low proficiency speakers, there was evidence of transfer. Across groups and conditions, both absolute and normalized (i.e., ratio) measures were incorporated in the analyses

Absolute measures of syllable duration: Absolute syllable durations were measured from the lower lip displacement signal for each of the target stimuli in the Bengali and English contexts. For example, as shown in Figure 1, the overall duration of the word “buffet” is approximately 0.7 seconds (sec), with the initial weak and final strong syllables occupying 0.3 sec and 0.4 sec of the movement duration, respectively.

Absolute measures of movement amplitude: Absolute amplitude values were measured from the lower lip displacement signal for the opening movements for each of the target syllables in the Bengali and English conditions. Prior work has shown that opening and closing movements show similar degrees of relative amplitude within a strong or a weak syllable (Goffman, 1999; Goffman & Malin, 1999) and only opening movements were included to reduce the complexity of the data analysis. As illustrated in Figure 1, the absolute amplitude values derived from the displacement record for the initial weak syllable in “buffet” are approximately 6.5 mm and the second strong syllable approximately 8.5 mm.

Ratio analysis for trochaic and iambic sequences: Since the relative amplitude and duration of weak compared to strong syllables is the measure of interest, a ratio of weak to strong syllables was computed based on the opening movement of each syllable (for the amplitude ratio) and the entire duration of each syllable (for the duration ratio). To illustrate using the example presented in Figure 1, the absolute duration values are approximately 0.3 sec and 0.4 sec (weak to strong). Therefore, the modulation ratio for duration is approximately 0.75. Similarly, the modulation ratio for amplitude in this example is 0.76 (6.5 mm to 8.5 mm). The stressed syllable always served as the anchor in the modulation analysis. Thus a ratio of less than 1 revealed modulation in the expected direction. Conversely, a ratio of greater than 1 showed that the speakers incorporated the non-target stress pattern in their production.

Statistical comparisons—Because of the potential inherent differences among English and Bengali segments, English and Bengali language contexts were analyzed separately. Statistical analyses included mixed ANOVAs with an alpha level set at .05. Experimental groups (e.g., early-high, late-low and monolinguals for English context analyses; early-high and late-low groups for Bengali context analyses) served as the between subject factor and stress pattern (trochaic and iambic), word (e.g., bible and buffet) and syllable position (first and second; included only for the analyses of absolute measures) as within subject factors. For perceptual judgment analyses, experimental groups (early-high and late-low) served as the between subject factor and stress pattern (trochaic and iambic), syllable position (first and second), and word (e.g., baboon and buffet) as within subject factors.

Results

Kinematic Correlates and Transfer of Lexical Stress

Absolute duration as a kinematic correlate of stress—In the English language context, to examine the influence of language experience/proficiency on production of strong and weak syllable durations, speakers from the high (n=10), the low (n=10) and the monolingual (n=10) groups were compared. Mean syllable duration data are presented in Figure 2 (left panel). No significant group differences were observed, $F(2, 27) = .91$, $p = .41$, and there was no significant influence of stress, $F(1, 27) = .032$, $p = .86$. There was no significant influence of words, $F(1, 27) = 1.63$, $p = .21$, and no words by group interaction, $F(2,27) = .19$, $p = .83$. However, there was a significant syllable position by stress by group interaction, $F(2, 27) = 6.25$, $p = .006$, $\eta_p^2 = .32$. Post-hoc testing (Tukey HSD) revealed that, in the trochaic condition, all three groups produced relatively longer initial strong syllables than final weak syllables. In the iambic condition, only the monolinguals produced significantly longer final strong syllables than initial weak syllables.

In the Bengali (L1) context, the analyses of lexical stress included only the early-high (n=10) and the late-low (n=10) groups. Mean syllable durations are presented in Figure 2 (right panel). Unlike the English context, in Bengali, the late-low group produced longer syllable durations than the early-high group, $F(1, 18) = 5.25$, $p = .03$, $\eta_p^2 = .23$. As expected, there was a main effect of word, $F(1, 18) = 4.55$, $p = .04$, $\eta_p^2 = .23$, with no word by group interaction, $F(1, 18) = .03$, $p = .86$, or stress by word by group interaction, $F(1, 18) = .002$, $p = .97$. However, a syllable position by stress interaction was observed, $F(1, 18) = 50.22$, $p < .001$, $\eta_p^2 = .74$. Post-hoc testing (Tukey HSD) revealed that the initial strong syllables in trochees were longer than the final weak syllables. No significant difference was observed between initial weak and final strong syllables in the iambic condition. There was no syllable position by stress by group interaction, $F(1, 18) = .51$, $p = .48$.

Relative duration as an index of transfer—To normalize the duration relations between strong and weak syllables, ratios of syllable durations were also examined. The data for the English context are presented in Figure 3 (left panel). The groups differed, $F(2, 27) = 11.83$, $p < .001$, with the monolinguals using modulation as targeted; monolingual speakers differed significantly from both groups of bilingual speakers. The early-high and the late-low groups did not differ from each other in their production of the English stress contrast. Trochees were produced with more target modulation than iambs, $F(1, 27) = 34.61$, $p < .001$.

When the ratios of syllable durations were calculated (Figure 3, right panel) in the Bengali context, and the early-high (n = 10) and the late-low (n=10) groups were compared, no effect of group was observed, $F(1, 18) = .06$, $p = .80$. There was a main effect of stress, $F(1, 18) = 9.34$, $p = .006$, $\eta_p^2 = .34$. Trochees were produced with the expected ratio of strong-to-weak syllables. However, iambic targets were produced with a trochaic rhythm (i.e., a relatively long initial weak syllable followed by a relatively short final strong syllable).

Absolute amplitude as a kinematic correlate of stress—Influences of L2 proficiency on the production of syllable amplitude in both English and Bengali contexts were also examined. In the English context, mean syllable amplitude values for the opening movements for each of the target syllables are presented in Figure 4 (left panel). Similar to the syllable duration results, the three groups did not differ, $F(2, 27) = 2.02$, $p = .15$. Predictably, a main effect of word was observed, $F(1, 27) = 16.41$, $p < .001$, $\eta_p^2 = .38$, but there was no stress by word by group interaction, $F(2, 27) = 2.98$, $p = .06$. There was a syllable position by stress by group interaction, $F(2, 27) = 7.75$, $p = .002$, $\eta_p^2 = .36$. Post-hoc testing (Tukey HSD) revealed that, in the trochaic condition, the early, the late and the monolingual groups produced relatively larger initial strong than final weak syllables. In the iambic condition, the early and the monolingual groups produced similar amplitude of movement across strong and weak syllables. However, similar to the trochaic targets, the late group produced larger initial syllables in the iambic condition.

Effects of L2 proficiency on syllable amplitude were also assessed in the Bengali context (Figure 4, right panel). Again in Bengali, high and low proficiency groups did not differ, $F(1, 18) = 2.32$, $p = .14$. There was no stress by word by group interaction, $F(1, 18) = .54$, $p =.47$. However, there was a syllable position by stress by group interaction, $F(1, 18) = 11.23$, $p = .003$, $\eta_p^2 = .38$. Post-hoc testing (Tukey HSD) revealed that both proficiency groups produced significantly larger initial syllables in trochaic and iambic words. That is, regardless of the prosodic target, the initial syllables had larger opening amplitude values, which is characteristic of the trochaic stress pattern.

Relative amplitude as an index of transfer—Ratios of weak to strong syllables were computed based on the opening movement of each syllable. Ratios of opening movement amplitudes in the English context are shown in Figure 5 (left panel). The groups did not differ, $F(2, 27) = 1.69$, $p = .20$. There was a main effect of stress, $F(1, 27) = 60.25$, $p < .001$, $\eta_p^2 = .69$, with trochees modulated as expected. Iambs, like trochees, were produced with larger movements in the initial weak syllable followed by smaller movements in the final strong syllable. Thus, iambs and trochees were differentiated with movement duration, but not amplitude. As illustrated in Figure 5, this result appeared driven by the word “baboon.” Recall that this word contains a rounded vowel in the second syllable, and therefore amplitude in the SI dimension may be less pronounced. Similarly, the groups did not differ in the Bengali context (Figure 5, right panel), $F(1, 18) = 1.82$, $p = .19$. A main effect of stress was observed, $F(1, 18) = 40.87$, $p < .001$, $\eta_p^2 = .69$, with trochees showing appropriate modulation toward the stress target compared with iambs. Iambs were modulated using a trochaic rhythm.

In summary, as reported previously (Hayes & Lahiri, 1991), Bengali has a fixed trochaic stress pattern. However, there is evidence of transfer in the L2 (English) context, in that Bengali speakers, especially those who are more proficient, include duration but not amplitude cues in their marking of iambic stress.

Perceptual Judgment: Proficiency Effect

Only the early-high (n=10) and the late-low (n=10) groups were compared. Mean accent ratings are shown in Figure 6. Analyses revealed that the early-high group received higher native-like accent ratings than the late-low group, $F(1, 18) = 10.48$, $p = .004$, $\eta_p^2 = .37$. A main effect of stress was also observed, $F(1, 18) = 21.35$, $p < .001$, $\eta_p^2 = .54$, with trochees (i.e., bible and marble) receiving significantly higher nativity ratings than iambs (i.e., baboon and buffet). There was no stress by group interaction, $F(1, 18) = 1.09$, $p = .30$ and no stress by word by group interaction, $F(1, 18) = .22$, $p = .64$. Overall, as expected, native English listeners judged word productions of the early-high group as more native-like than the late-low group, with trochees receiving higher rankings than iambs.

Discussion

A major goal of the present research was to observe interactions between language experience and the production of trochaic and iambic words. More specifically, we examined how speakers of a trochaic language, Bengali, produce stress sequences that are native (i.e., trochaic) and non-native (i.e., iambic) to their first language. In addition, through examination of productions of stress sequences, we expected to gain insight into a lexical stress “transfer” phenomenon which, according to many researchers, is a major contributor to non-native speakers’ “foreign accent” (e.g., Archibald, 1993; Major 2001). Using absolute and relative measures of movement duration and amplitude (i.e., kinematic correlates of stress) as indices, we attempted to understand how monolingual English speakers and non-native speakers’ marked trochaic and iambic prosodic targets.

Comparisons between Monolingual English and Bilingual Bengali-English Speakers

In English, all non-native speakers produced the trochaic rhythm with longer duration and larger amplitude for the initial strong than the final weak syllables. It was predicted that, similar to prior results, trochaic words would be produced with relatively equal weight across strong and weak syllables (Goffman, 1999; Goffman & Malin, 1999; Goffman, Heisler, & Chakraborty, 2006). This finding was not replicated here, with even the monolingual English speakers producing larger and longer movements in initial stressed than final unstressed syllables. One explanation for this result is that the present study used real rather than novel words, and thus these were not controlled for segmental content; characteristics of the vowel in the stressed syllable may have influenced the degree of temporal and spatial modulation observed. Another possibility is that the target words were embedded in sentence internal position, while in the majority of prior studies final position effects may have played a role in the degree of modulation observed. In prior studies, adults showed some spatial and temporal stress modulation in trochees, just to a lesser extent to that observed in iambs. What is critical for the present results, however, is that both monolingual and bilingual speakers produced similarly well formed trochaic sequences. There were no group differences in the production of the kinematic correlates of stress in the trochaic context.

However, for the iambic targets, bilingual speakers continued to produce a trochaic rhythm, with temporal and spatial correlates of stress consistent with a trochaic rather than an iambic rhythm. Both high and low proficiency non-native Bengali speakers' incorporated their preferred trochaic structure into their production of iambic targets. In addition, based on visual inspection of the data (Figures 2 through 5), it appeared that all participants, monolingual and bilingual, predominantly used temporal variation to produce the target prosodic modulation for the iambic word, "baboon." It is plausible that the vowel in the syllable [bun] requires reduced movement amplitude in the superior-inferior dimension, since it is predominantly marked by rounding. Further, it is important to consider that English nouns statistically include more trochees than iambs and, in future studies, it would be important to assess the influence of these statistical tendencies on the production of prosodic patterning.

Kinematic Correlates of Prosodic Structure in Bengali Speakers

In Bengali, no speaker produced an iambic rhythm, which is consistent with the observation that, regardless of grammatical class, the first syllable has to be stressed (Chatterji, 1921; Hayes & Lahiri, 1991; Klaiman, 1987). In fact, the trochaic rhythm was so robust that, in spite of the word final lengthening effect, a trochaic rhythm was observed. Overall, in this study, we found converging articulatory evidence that Bengali is a trochaic language (Chatterji, 1921; Hayes & Lahiri, 1991; Klaiman, 1987). Of course a larger corpus is required in future studies, one that includes other lexical types and grammatical classes. Because of the goals of the present study, words were selected that were meaningful in both Bengali and English. These loan words may not be entirely consistent with Bengali phonology. In addition, acoustic analyses would be useful to reveal how other parameters of stress, such as fundamental frequency, are manipulated in Bengali.

In prior work, both amplitude and duration have been identified as kinematic correlates of lexical stress (e.g., Beckman & Edwards, 1994; de Jong 1995; Fowler, 1995; Goffman, 1999). In the present study non-native speakers, especially less experienced and proficient speakers, manipulated duration to achieve the target stress patterns. In the English condition, the late-low group primarily used duration, even though the early-high group, similar to the monolinguals, used duration and amplitude both. In the Bengali context, all non-native speakers were similar and predominantly manipulated movement duration. It seems that early-high proficiency speakers are more flexible in manipulating these two kinematic parameters depending upon the target language; in English they manipulated both duration and amplitude, whereas in Bengali they usually varied only duration. The late-low group speakers' were relatively inflexible, as they predominantly manipulated duration in both language contexts. It could also be that, in Bengali, stress marking is executed by varying temporal but not spatial aspects of articulation.

Movement Modulation as an Index of Lexical Stress Production and Transfer

Recall that a primary hypothesis of this research was that non-native speakers, especially those with late exposure and low proficiency in English, will transfer, and thus over-generalize, the Bengali trochaic stress pattern. Our results offer preliminary evidence to support this hypothesis. Across the two language contexts, non-native speakers in general, and more specifically the late-low group, produced the trochaic rhythm in the iambic context. Non-native speakers appear to over-generalize the Bengali trochaic stress pattern, which in turn suggests L1 to L2 transfer of lexical stress at the level of movement execution.. More specifically, non-native speakers' frequent production of trochaic rhythm for iambic targets could be considered as an instance of negative transfer. However, even though adult non-native speakers of L2 retain traces of their L1, L2 stress patterns are amenable to change (Archibald, 1995). Non-native speakers might be capable of resetting their parameters to approximate the stress pattern specified by the target L2. Through language-specific readjustment, non-native speakers can potentially better approximate native-like stress patterns in L2. For example, in this study, in the production of English words with a target iambic rhythm, both high and low proficiency groups showed duration modulation consistent with an iambic rhythm, but amplitude modulation for the same targets with a trochaic rhythm. Non-native speakers never collapsed trochaic and iambic categories completely. They either used duration or amplitude, or at times both parameters to differentiate trochaic from iambic targets. This suggests that adults can differentially represent native and non-native lexical stress patterns, even if they are exposed to the non-native stress patterns long after puberty. It is also possible that certain parameters, such as temporal aspects of lexical stress, are particularly amenable to linguistic modifications.

Perceptual Judgment of Accent in Iambic and Trochaic Words

A primary motivation for the perceptual judgment analysis was to examine differences in foreign accent perception as a function of L2 proficiency and to confirm our categorization of high and low proficiency groups. Most importantly, we were interested in understanding prosodic effects on judgment of accent. Prior studies have demonstrated that L2 pronunciation of early bilinguals sounded more native-like than did that of late bilinguals (e.g., Flege, et al., 1997; Guion, et al., 2000a; also see Piske, et al., 2001, for a review). Our results are consistent with previous findings as well as with our prediction; pronunciation of the early-high group speakers was judged to be more “native-like” than the late-low proficiency group.

Turning to more specific results, comparatively lower accent ratings were obtained for iambic targets “baboon” and “buffet” than trochaic targets “bible” and “marble.” This provides evidence that native speakers’ perceived “non-nativeness” in iambs and trochees sounded more native-like than iambs, whether the words were produced by the high or low proficiency speakers of L2. Such an interpretation could stem from the predominance of trochaic rhythm in bisyllabic nouns in English (Coltheart, 1981; Kelly, 2003). Such contrasts in ratings between trochaic and iambic words could also be driven by the fact that, in Bengali, the first syllable has to be stressed and hence speakers, regardless of their proficiency level, sounded more non-native when the target demanded a weak-strong stress sequence.

The perception of foreign accent is a global measure, in which listeners base their judgments on multiple factors that incorporate segmental and prosodic phonological variables, along with vocabulary choice, and syntactic structure. There are few studies, however, which have examined the influence of prosody on foreign accent rating. Relying on acoustic analyses, previous studies have reported that prosody is critical in the perception of accent (Anderson-Hsieh, Johnson, & Koehler, 1992; Boula de Mareüil, & Vieru-Dimulescu, 2006; Gilbert, 1984; Munro, 1995). Specifically, temporal variation, which is an index of prosodic modulation, is reported to be an important contributor to the perception of foreign accent (Tajima, Port, & Dalby, 1997). In the present study, listeners judged nouns that differed in stress. They were not asked to focus specifically on stress cues and other factors may have contributed to their evaluation, such as the etymology of the chosen stimuli (e.g., French “buffet” versus Latin/Greek “bible”), the frequency of trochaic versus iambic nouns in standard American English, and the degree of familiarity with specific words (e.g., “baboon” versus “bible”). In future work, it would be informative to sort out the contributions of specific cues to listeners ratings of nativity.. However, it appears that when other variables are fairly well controlled, prosodic factors indeed play an important role the in perception of degree of foreign accent, with trochees judged as more English-like than iambs.

Acknowledgments

We are grateful to Laurence Leonard, Christine Weber-Fox, and Janna Berlin for invaluable assistance with many phases of this work. A special thanks to Karen Forrest and all the reviewers. This research was supported by the National Institutes of Health (National Institute of Deafness and other Communicative Disorders) grant DC04826.

References

Anderson-Hsieh J, Johnson R, Koehler K. The Relationship Between Native Speaker Judgments of Nonnative Pronunciation and Deviance in Segmentals, Prosody, and Syllable Structure. Language Learning. 1992; 42(4):529–555.

Archibald J. Transfer of L1 parameter settings: Some empirical evidence from polish metrics. Canadian Journal of Linguistics. 1992; 37:301–339.

Archibald, J. Language learnability and L2 phonology: The acquisition of metrical parameters. Dordrecht/Boston/London: Kluwer Academic; 1993.

Archibald, J. Phonological acquisition and phonological theory. Hillsdale, N.J: Lawrence Erlbaum Associates; 1995.

Asher JJ, Garcia R. The optimal age to learn a second language. The Modern Language Journal. 1969; 53:334–341.

Beckman, ME.; Edwards, J. Articulatory evidence for differentiating stress categories. In: Keating, PA., editor. Phonological Structure and Phonetic Form: Papers in Laboratory Phonology III. Cambridge University Press; 1994. p. 7-33.

Bernardini P, Schlyter S. Growing syntactic structure and code-mixing in the weaker language: The Ivy Hypothesis. Bilingualism: Language and Cognition. 2004; 7:49–69.

Birdsong, D. Second language acquisition and the critical period hypothesis. Mahwah, NJ: Lawrence Erlbaum Associates; 1999.

Boersma, P.; Weenink, D. Praat: doing phonetics by computer (Version 5.1.12) [Computer program]. 2009. Retrieved August 4, 2009, from http://www.praat.org/Boulade

Browman CP, Goldstein L. Articulatory phonology: An overview. Phonetica. 1992; 49:155–180. [PubMed: 1488456]

Mareüil P, Vieru-Dimulescu B. The Contribution of Prosody to the Perception of Foreign Accent. Phonetica. 2006; 63(4):247–267. [PubMed: 17293645]

Chakraborty R, Goffman L, Smith A. Physiological Indices of Bilingualism: Oral-Motor Coordination and Speech Rate in Bengali-English Speakers. Journal of Speech, Language & Hearing Research. 2008; 51:321–332.

Chatterji SK. Bengali Phonetics. Bulletin of the School of Oriental and African Studies. 1921; 2:1–25.

Cho, T. Manifestation of prosodic structure in articulation: Evidence from lip kinematics in English. In: Goldstein, LM.; Whalen, DH.; Best, CT., editors. Laboratory phonology 8: Varieties of phonological competence. Berlin & New York: Mouton de Gruyter; 2002.

Coltheart M. The MRC psycholinguistic database. The Quarterly Journal of Experimental Psychology. 1981; 33:497–505.

de Jong KJ. The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticulation. Journal of the Acoustical Society of America. 1995; 97:491–504. [PubMed: 7860828]

Engstrand O. Articulatory correlates of stress and speaking rate in Swedish VCV utterances. Journal of the Acoustical Society of America. 1988; 83:1863–1875. [PubMed: 3403802]

Flege JE. Factors affecting degree of perceived foreign accent in English sentences. Journal of the Acoustical Society of America. 1988a; 84:70–79. [PubMed: 3411056]

Flege JE. The development of skill in producing word-final /p/ and /b/: Kinematic parameters. Journal of the Acoustical Society of America. 1988b; 84:1639–1652. [PubMed: 3209769]

Flege JE, Fletcher KL. Talker and listener effects on degree of perceived foreign accent. Journal of the Acoustical Society of America. 1992; 91:370–389. [PubMed: 1737886]

Flege J, Frieda E, Nowaza T. Amount of native-language (L1) use affects the pronunciation of an L2. Journal of Phonetics. 1997; 25:169–186.

Flege J, Munro M, MacKay I. Factors affecting degree of perceived foreign accent in a second language. Journal of the Acoustical Society of America. 1995; 97:3125–3134. [PubMed: 7759652]

Flege JE, Yeni-Komshian G, Liu H. Age constraints on second language acquisition. Journal of Memory & Language. 1999; 41:78–104.

Fowler, CA. Correlates of contrastive stress accent. In: Beel-Berti, F.; Raphael, L., editors. Producing speech: Contemporary isues. New York: AIP Press; 1995. p. 355-373.

Gilbert, J. Pronunciation and listening comprehension. In: Morley, HJ., editor. Current perspectives on pronunciation. Washington, DC: TESOL; 1984. p. 33-39.

Goffman L. Prosodic influences on speech production in children with specific language impairment and speech deficits: Kinematic, acoustic, and transcription evidence. Journal of Speech Language & Hearing Research. 1999; 42:1499–1517.

Goffman L. Kinematic differentiation of prosodic categories in normal and disordered language development. Journal of Speech Language & Hearing Research. 2004; 47:1088–1102.

Goffman L, Malin C. Metrical effects on speech movements in children and adults. Journal of Speech Language & Hearing Research. 1999; 42:1003–1015.

Goffman L, Heisler L, Chakraborty R. Mapping of prosodic structure onto words and phrases in children's and adults' speech production. Language and Cognitive Processes. 2006; 21:25–47.

Guion SG, Flege JE, Loftin JD. The effect of L1 use on pronunciation in Quichua-Spanish bilinguals. Journal of Phonetics. 2000a; 28(1):27–42.

Guion SG. Knowledge of English word stress patterns in early and late Korean-English bilinguals. Studies in Second Language Acquisition. 2005; 27:503–533.

Hammill, DD.; Brown, VL.; Larsen, SC.; Weiderholt, JL. Test of Adolescent and Adult Language. 3. Austin, TX: Pro-Ed, Inc; 1994.

Hayes, B. Metrical stress theory. Chicago: University of Chicago Press; 1995.

Hayes B, Lahiri A. Bengali intonational phonology. Natural Language and Linguistic Theory. 1991; 9:47–96.

Heredia R, Altarriba J. Bilingual language mixing: Why do bilinguals code-switch. Current Directions in Psychological Science. 2001; 10:164–168.

Jarvis S, Odlin T. Morphological type, spatial reference, and language transfer. Studies in Second Language Acquisition. 2000; 22:535–556.

Jones M. Transfer and changing linguistic norms in Jersey Norman French. Bilingualism: Language and Cognition. 2005; 8:159–175.

Kelly MH. Word onset patterns and lexical stress in English. Journal of Memory and Language. 2003; 50:231–244.

Klaiman, MH. Bengali. In: Comrie, B., editor. The World's Major Languages. Croon Helm: London and Sydney; 1987. p. 490-513.

Klien, W. Language acquisition at different ages. In: Magnusson, D., editor. The lifespan development of individuals: Behavoral, neurobiological, and psychological perspectives. A synthesis. New York: Cambridge University Press; 1995. p. 244-264.

Lenneberg, EH. Biological foundations of language. New York: Wiley; 1967.

Long M. Maturational constraints on language development. Studies in Second Language Acquisition. 1990; 12:251–286.

Mathworks, Inc. Matlab: Higher Performance numeric computation and visualization software [computer program]. Natick, MA: Author; 1993.

Major, RC. Foreign accent : the ontogeny and phylogeny of second-language phonology. Mahwah, N.J: Erlbaum; 2001.

McCully C. Exaptation and English stress. Language Sciences. 2002; 24(3–4):323–344.

Missaglia F. Contrastive prosody in SLA: An empirical study with adult Italian learners of German. Proceedings of the XIVth International Congress of Phonetic Sciences. 1999; 1:555–558.

Moyer A. Ultimate attainment in L2 phonology. Studies in Second Language Acquisition. 1999; 21:81–108.

Munhall K, Ostry DJ, Parush A. Characteristics of velocity profiles in speech movements. Journal of Experimental Psychology. 1985; 11:457–474. [PubMed: 3161986]

Munro MJ. Nonsegmental factors in foreign accent: ratings of filtered speech. Studies in Second Language Acquisition. 1995; 17:17–34.

Mooshammer C, Fuchs S. Stress distinction in German: Simulating kinematic parameters of tongue tip gestures. Journal of Phonetics. 2002; 30:337–355.

Nissen SL, Dromey C, Wheeler C. First and second language tongue movements in Spanish and Korean bilingual speakers. Phonetica. 2007; 64:201–216. [PubMed: 18421243]

Odlin, T. Language Transfer: Cross-Linguistic Influence in Language Learning. Cambridge Applied Linguistics. Cambridge University Press; United Kingdom: 1989.

Patkowski M. Age and accent in a second language: A reply to James Emil Flege. Applied Linguistics. 1990; 11:73–89.

Pavlenko A, Jarvis S. Bidirectional transfer. Applied Linguistics. 2002; 23:190–214.

Penfield, W.; Roberts, L. Speech and brain mechanisms. New York: Atheneum; 1959.

Piske T, Mackay I, Flege J. Factors affecting degree of foreign accent in an L2: a review. Journal of Phonetics. 2001; 29:191–215.

Prince, A. Papers from the Twenty-sixth Regional meeting, Chicago Linguistic Society. Vol. 2. Chicago: Chicago Linguistic Society, University of Chicago; 1990. Quantitative consequences of rhythmic organization; p. 255-298.

Scovel, T. A time to speak: A psycholinguistic inquiry into the critical period for human speech. New York: Newbury House/Harper & Row; 1988.

Seliger, H. Implications of multiple critical period hypotheses for second language learning. In: Ritchie, W., editor. Second Language Acquisition Research. Academic Press; New York: 1978.

Smith A, Johnson M, McGillem C, Goffman L. On the assessment of stability and patterning of speech movements. Journal of Speech Language & Hearing Research. 2000; 43:277–286.

Smith A, Goffman L. Stability and patterning of speech movement sequences in children and adults. Journal of Speech, Language, and Hearing Research. 1998; 41:18–30.

Smith A, Zelaznik H. The development of functional synergies for speech motor coordination in childhood and adolescence. Developmental Psychobiology. 2004; 45:22–33. [PubMed: 15229873]

Southwood M, Flege J. Scaling foreign accent: direct magnitude versus interval scaling. Clinical Linguistics & Phonetics. 1999; 13:335–349.

Summers WV. Effects of stress and final-consonant voicing on vowel production: Articulatory and acoustic analyses. Journal of the Acoustical Society of America. 1987; 82:847–863. [PubMed: 3655120]

Tajima K, Port R, Dalby J. Effects of temporal correction on intelligibility of foreign-accented English. Journal of Phonetics. 1997; 25(1):1–24.

Treffers-Daller J, Mougeon R. The role of transfer in language variation and change: Evidence from contact varieties of French. Bilingualism: Language and Cognition. 8:93–98.

Weinreich, U. Languages in Contact. New York: Linguistic circle of New York; 1953.

Wode H. The beginning of non-school room L2 phonological acquisition. International Review of Applied Linguistics in Language Learning. 1978; 16:109–125.

Wolff, P.; Ventura, T. When Russians learn English: How the meaning of causal verbs may change; Proceedings of the Twenty-Seventh Annual Boston University Conference on Language Development; 2003. p. 822-833.

Yeni-Komshian GH, Flege JE, Liu S. Pronunciation proficiency in the first and second languages of Korean-English bilinguals. Bilingualism. 2000; 3:131–149.

Zsiga EC. Articulatory timing in a second language. Studies in Second Language Acquisition. 2003; 25:399–432.

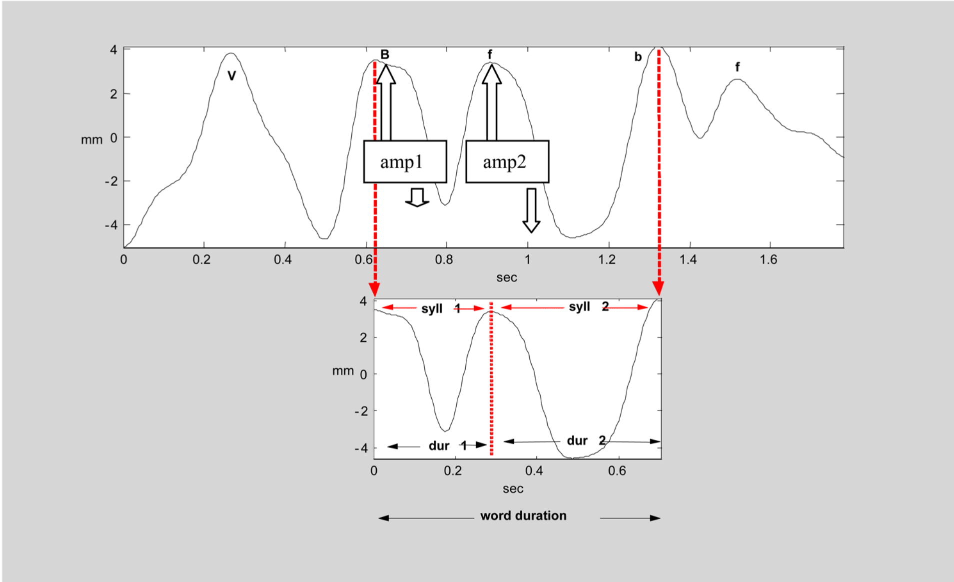

Figure 1.
Illustration of extraction of the word "buffet" from a single production of the carrier phrase "I have said buffet before." The lower lip displacement (in the superior-inferior dimension) was used to segment the onset and offset points, as illustrated by the vertical lines.

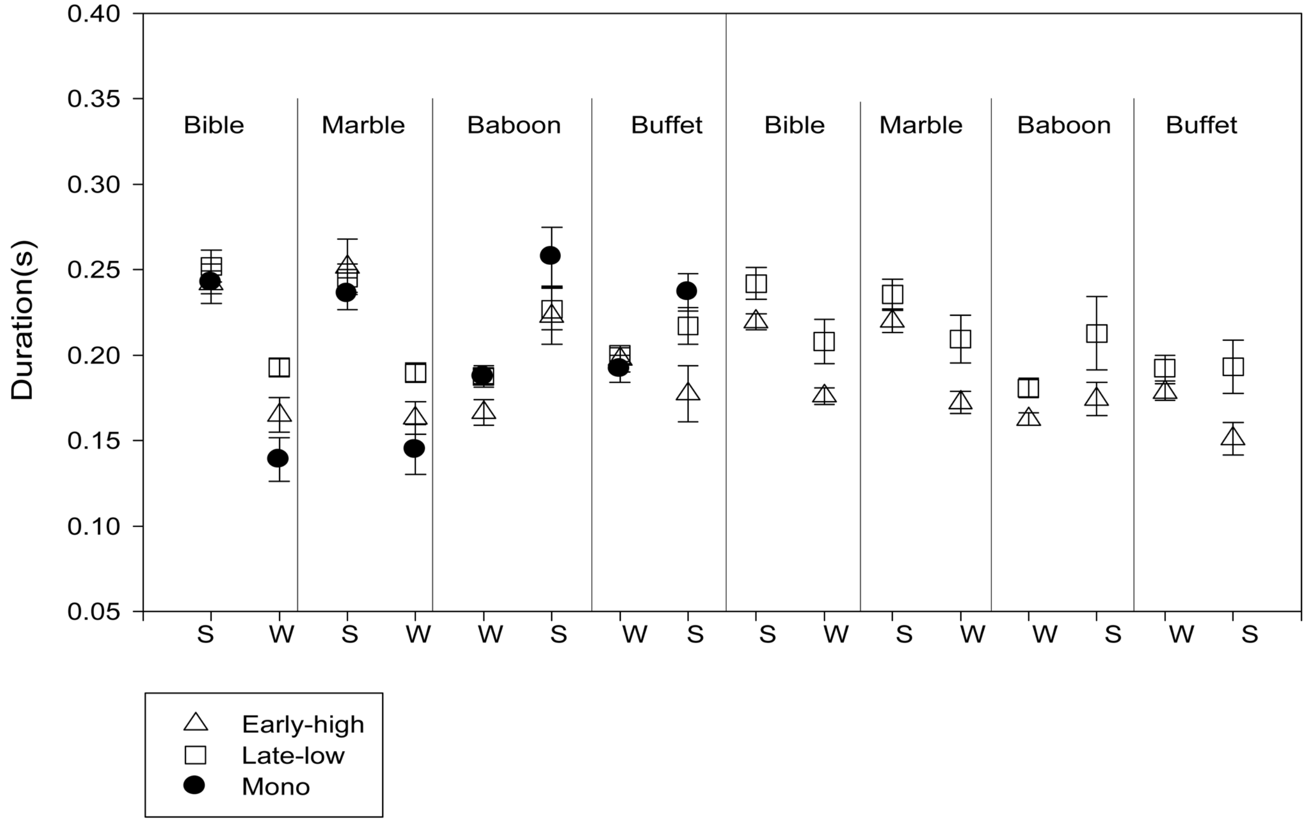

Figure 2.
Absolute syllable duration (in seconds). Data from high and low proficiency and monolingual (mono) speakers for the English context are included (left panel). The constituent strong (S) and weak (W) syllables for the trochaic words(S-W) and the iambic words (W-S) are presented. The right panel represents data from early-high and late-low proficiency for the Bengali context. In the Bengali context, constituent syllables for the iambic targets are also marked as weak (W) – strong (S), even though we acknowledge that Bengali does not allow iambic stress placement. Error bars represent standard errors.

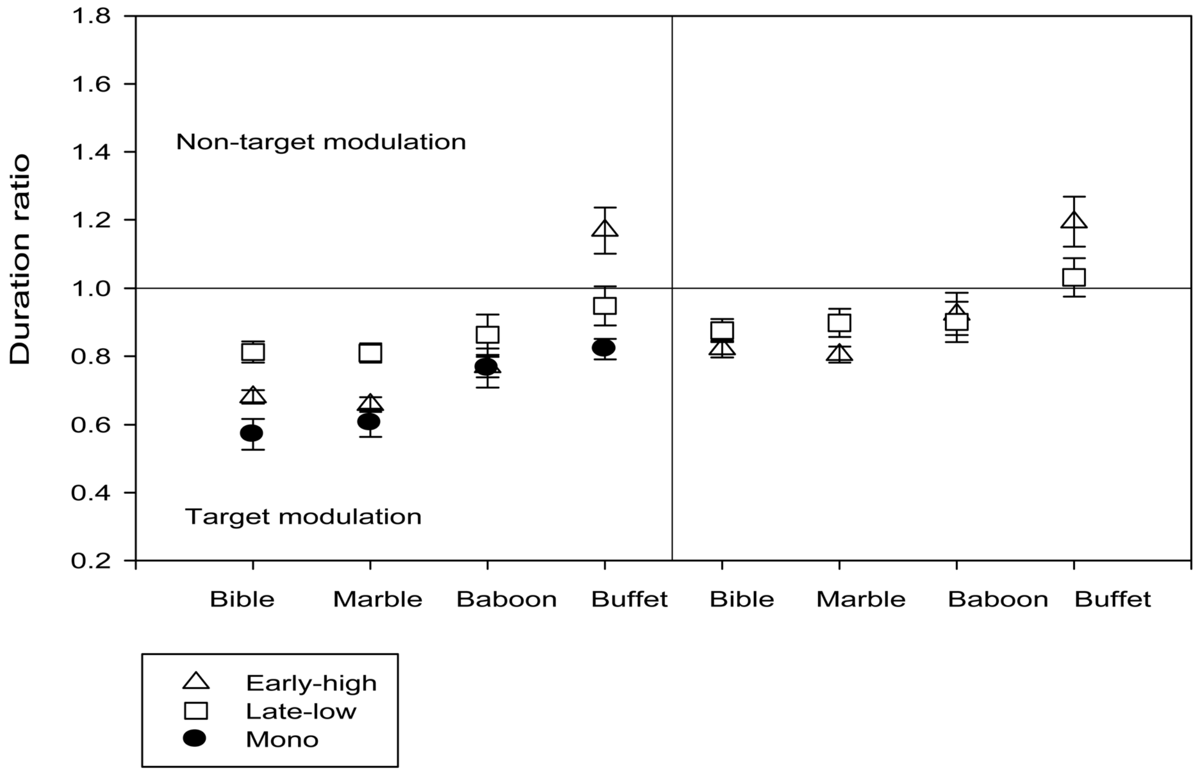

Figure 3.
Duration ratio of weak to strong syllables. Data from early-high and late-low proficiency and monolingual (mono) speakers for the English context are included in the left panel. Data from early-high and late-low proficiency speakers for the Bengali context are included in the right panel. Values that are greater than 1 (marked with horizontal line) are incorrect stress patterns. Error bars represent standard errors.

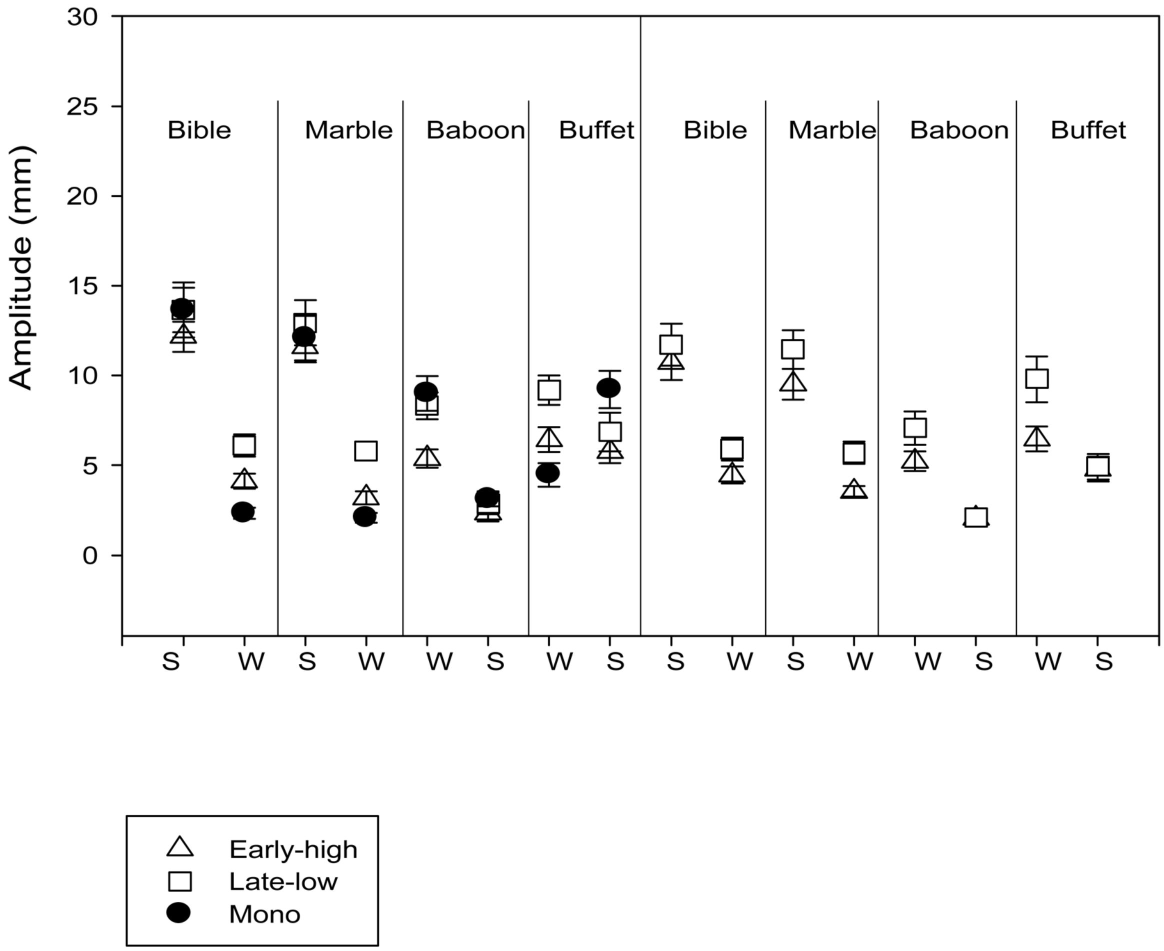

Figure 4.
Absolute syllable amplitude (in mm). Left panel represents data from the English context and right panel from the Bengali context. The constituent strong (S) and weak (W) syllables for the trochaic words(S-W) and the iambic words (W-S) are presented. Error bars represent standard errors.

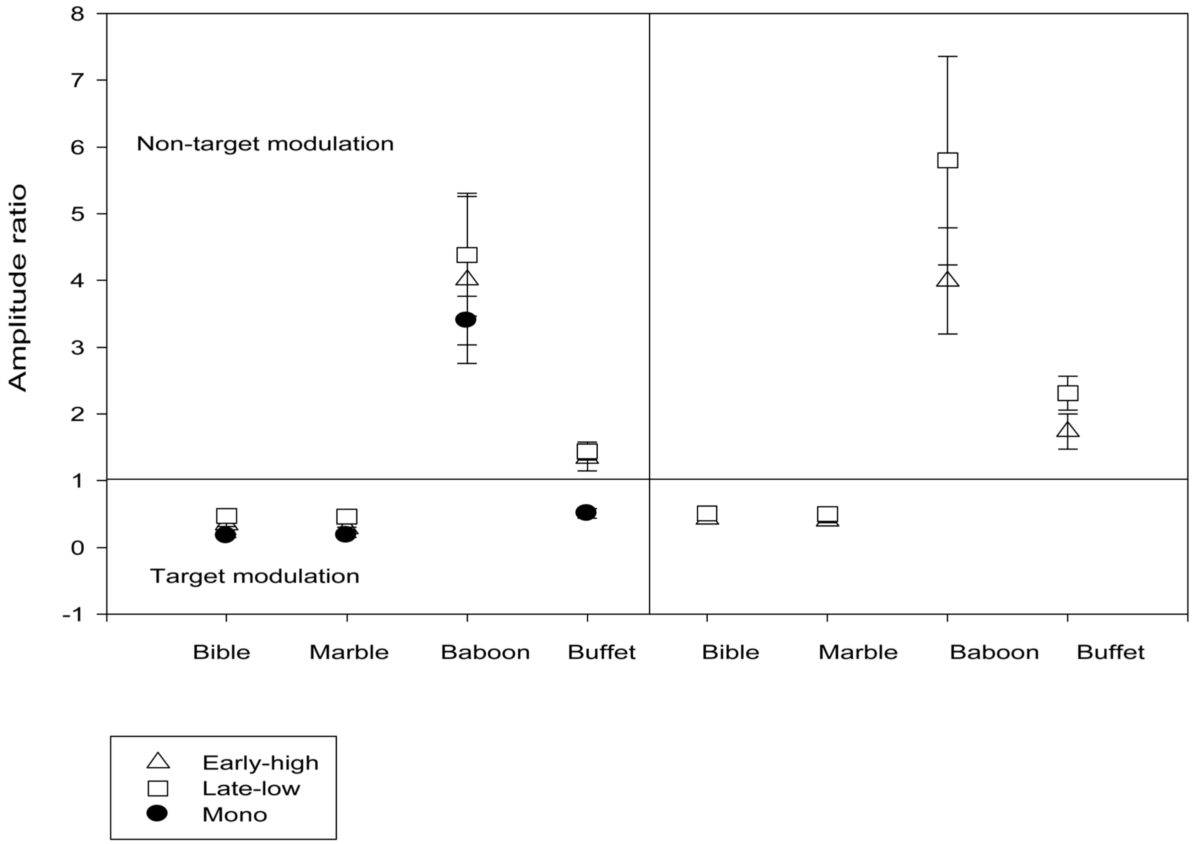

Figure 5.
Opening amplitude ratio of weak to strong syllables. Data from early-high and late-low proficiency and monolingual (mono) speakers are included in the left panel. Data from early-high and late-low proficiency speakers for the Bengali context are included in the right panel. Values that are greater than 1 (marked with horizontal line) are incorrect stress patterns. Error bars represent standard errors.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

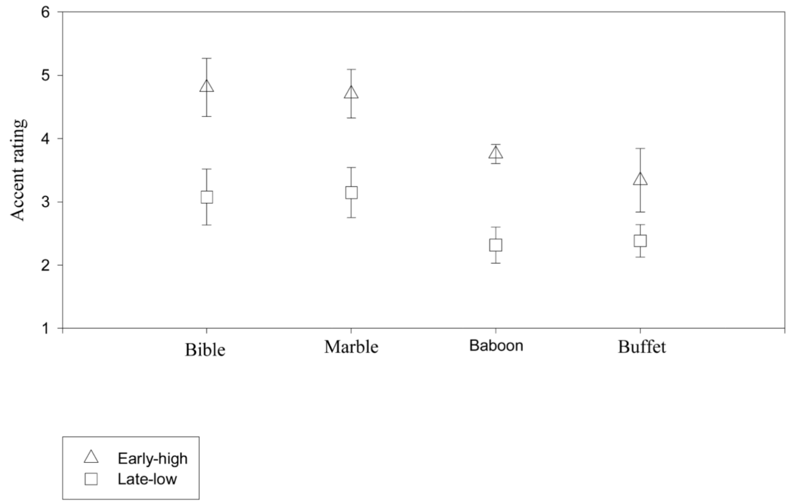

Figure 6.
Accent ratings of 20 bilingual participants on a 9-point metathetic scale, based on perceptual judgments of 6 monolingual native speakers of American English. In the scale, 9 represented 'very native-like' and 1 represented 'very non-native-like' productions. Error bars represent standard errors.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 1

Chronological age (CA), gender (G), age (in years) of arrival in the USA (AOA), scores on Speaking (Sp) Grammar Subtest and languages spoken (L; English = E, Bengali = B): Two Groups of Bilinguals and Monolinguals

Sub.	Early-high				Late-low				Monolingual		
	CA/G	AOA	Sp	L	CA/G	AOA	Sp	L	CA/G	Sp	L
1	24/F	22	26	B,E	26/F	24	9	B,E	22/M	21	E
2	26/M	23	21	B,E	26/M	24	3	B,E	21/F	23	E
3	26/F	24	20	B,E	25/F	21	6	B,E	24/F	27	E
4	33/M	31	29	B,E	35/F	30	9	B,E	20/F	20	E
5	26/M	23	15	B,E	30/M	28	6	B,E	22/M	24	E
6	33/F	31	19	B,E	28/M	24	10	B,E	23/F	26	E
7	27/M	25	17	B,E	35/M	31	5	B,E	21/M	19	E
8	25/F	22	25	B,E	26/M	23	9	B,E	21/F	22	E
9	34/F	29	26	B,E	27/F	24	10	B,E	22/F	25	E
10	30/F	25	23	B,E	30/F	25	3	B,E	24/M	23	E
Mean	28.4	25.5	21.4		28.8	25.5	7		22	23	
STD	3.75	3.54	3.75		3.68	3.20	2.75		1.33	2.58	