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Abstract

This study documents patterns of change in speech production in a multilingual with aphasia following a cerebrovascular accident (CVA). EC, a right-handed Hebrew-English-French trilingual man, had a left fronto-temporo-parietal CVA, after which he reported that his (native) Hebrew accent became stronger in his (second-language) English. Recordings of his pre- and post-CVA speech permitted an investigation of changes in his accent. In sentence and segment listening tasks, native American English (AE) listeners (n=13 and 15, respectively) judged EC's pre-CVA and post-CVA speech. EC's speech was perceived as more foreign-accented, slow, strained, and hesitant, but not less intelligible, post-CVA. Acoustic analysis revealed less coarticulation and longer vowel- and word-durations post-CVA. This case extends knowledge about perceptual and acoustic changes in speech production in multilinguals following CVAs. It is argued that EC's stronger accent post-CVA may have resulted from damage to the neuronal networks that led to impairment in his other language domains.

Stronger accent following a stroke: The case of a trilingual with aphasia

Language loss following aphasia can manifest in language-level impairments, such as anomia (word-finding difficulties) and semantic paraphasias (word substitutions) (Brookshire, 2007), and in speech-production impairments, such as apraxia of speech (difficulty in motor programming for speech production) (Kent & Rosenbek, 1983; Mauszycki, Wambaugh, & Cameron, 2010). In rare cases, atypical speech produced by monolinguals who did not speak another language before their stroke is perceived as spoken with a foreign accent and is termed 'Foreign Accent Syndrome' (FAS) (Whitaker, 1982; Perkins, Ryalls, Carson, & Whiteside, 2010). Bilingual and multilingual speakers with aphasia have been reported to exhibit the same types of language and speech deficits reported for monolinguals (Paradis, 2004). However, little has been published about changes in the degree of foreign accents of multilinguals in their non-native languages following a stroke.

In this paper, we review the main findings reported to-date about language and speech impairment in multilingual aphasia and findings reported for FAS. Subsequently, we present the case of a multilingual individual with aphasia who experienced language impairment in all of his languages following a stroke and reported that his second language (L2), English, became more accented after the stroke. Finally, we present data indicating that the reported change in level of accent was corroborated by naïve listener judgments and acoustic analysis.

Impairment and recovery in multilingual aphasia

Bilingual and multilingual speakers with aphasia typically experience comparable deficits in all of their languages, but cases demonstrating non-parallel deficit and recovery patterns have also been reported (e.g. Albert & Obler, 1978; Paradis, 2004). To explain patterns of non-parallel recovery, researchers have hypothesized differential language representation between or within the two cerebral hemispheres (e.g. Giussani, Roux, Lubrano, Gaini, & Bello, 2007). However, dynamic patterns of change in language accessibility following the aphasia onset on the one hand, and the finding of overlapping areas of neuronal activation in all languages of multilingual speakers reported in neuroimaging studies on the other hand, suggest chiefly shared language representation and processing. Indeed, some researchers have suggested that mechanisms of controlled inhibition and activation of the languages, rather than their underlying representation, are impaired (e.g. Abutalebi & Green, 2007).

The cases reported in the literature typically provide details about performance post-CVA in multilinguals, but little information can be found about degrees of accentedness in these languages. Two studies describing the possible return of a previously-held accent in multilinguals can be found in the literature. Roth, Fink, Cherney, and Hall (1997) described a 45-year old man with Broca's aphasia following a left parietal CVA, whose Dutch accent, which he had not had since his early childhood in Holland, returned in his English production. Similarly, Seliger, Abrams, and Horton (1992) report a 65-year old woman from New York who, after a left subcortical CVA, presented with normal language and an acquired Irish brogue in English, a dialect her mother had had and that the patient may have had.

FAS

When speech (usually accompanying aphasia and following a CVA) reveals a sudden development of foreign-sounding speech in a patient with no history of acquisition or use of other languages, this is termed FAS. Locations of lesions involved in FAS appear to be diverse, with most cases involving an anterior left-hemisphere lesion (Blumstein & Kurowski, 2006). According to Blumstein and Kurowski (2006: 349), an essential attribute of FAS is the 'sudden appearance of an unlearned generic accent'. Thus, if a patient reverts to an accent that had been in his/her linguistic repertoire, this fails to meet the criteria of FAS.

Possible explanations for FAS have included changes in muscular adjustment in speech production, tense vocal tract posture (Ryalls & Whiteside, 2006) and motor control problems (see Moen, 2000, for an overview). Kurowski, Blumstein, and Alexander (1996) suggest that the syndrome may reflect injury to different motor-output systems.

Regarding the return of an accent following a CVA, Seliger et al. (1992) refer to Jenkins, Merzenich, and Recanzone's (1990) evidence of cortical reorganisation a few hours after brain injury that plays a role in recovery. Jenkins et al. suggest that neural circuitry that was previously suppressed can become unmasked during brain injury. Seliger et al. propose that their patient's childhood Irish brogue may have become suppressed during her language development and that her neural circuitry representing an earlier time in development resurfaced post-CVA. Alternatively, they suggest that languages learned at different ages may be represented by distinct anatomical locations in the brain. They posit that their patient's 'New York accent center' was damaged, whereas her 'Irish accent center' (p. 1656) was relatively spared.

For Seliger et al.'s patient, as for the vast majority of FAS cases, no analyses of recordings from the patient's earlier speech patterns were available to verify whether her accent 'returned'. In fact, few acoustic studies of even post-CVA FAS speech exist, limiting the field's ability to define FAS (Coelho & Robb, 2001; Blumstein & Kurowski, 2006). A handful of studies have examined the acoustics of pre- vs. post-CVA utterances of speakers with FAS (Ingram, 1992; Kurowski et al., 1996; Dankovičová et al., 2001). One study (Perkins et al., 2010) has examined the speech of two individuals who had FAS while their speech was perceived as accented and after their normal speech patterns had recovered. Unlike for many FAS cases, EC's speech, examined seven years after the stroke, retained the post-CVA accent. To the authors' knowledge, no recordings of pre-CVA and post-CVA speech have been documented for cases in which multilinguals' accents were reported to have changed.

The present study

The present study relied on recordings of pre- and post-CVA speech to investigate changes in speech patterns of EC, a trilingual speaker with non-fluent aphasia. Hebrew was EC's native language; English was learned in school, beginning at ten years of age (although he was exposed to some English in his environment in the first three years of his life), and French was learned at age 16 via self-instruction and classes. EC was born in the US to Hebrew-speaking parents and moved to Israel at age three. EC moved to the US in his early twenties, then to France and Switzerland (Geneva), returning to the US at age 39. He holds a Ph.D. in physics. EC reported that he spoke French at home with his family, English at work and outside of the home, and Hebrew with relatives.

At the age of 42, EC incurred a CVA. Initial hospital records indicated an internal carotid artery dissection, revealed by a CT angiogram. A CT scan at the hospital, five days after the CVA, confirmed a massive infarct involving portions of the left frontal, temporal, and parietal lobes and basal ganglia. A follow-up CT scan three weeks after the CVA revealed that the infarct had become more discrete. Formal speech-language evaluation, including the Boston Diagnostic Aphasia Examination (Goodglass, Kaplan, & Barresi, 2001) and the Bilingual Aphasia Test (Paradis & Libben, 1987), diagnosed non-fluent, agrammatic aphasia without apraxia or dysarthria. Follow-up tests by the authors (see Goral, Levy, Obler, & Cohen, 2006; Goral, Levy, & Kastl, 2010) confirmed that EC experienced morpho-syntactic and lexical retrieval difficulties in sentence and discourse production, and slow speech, including hesitations and selfcorrections. His comprehension in all three languages was largely intact. At the time of the study, EC had residual aphasia, with his French language production the most impaired, followed by his English. His most preserved language production was in Hebrew. EC reported that, prior to his CVA, he spoke English and French with only a mild Hebrew accent, but that, following his CVA, a strong Hebrew accent returned in both languages. He stated that his family and friends also remarked that he had a strong Hebrew accent after the CVA.

Based on recordings of EC's speech (see Method section), the following characteristics of EC's pronunciation were described by a naïve native speaker of English, a research assistant enrolled in a speech-language pathology programme, and confirmed by the third author, a native English-speaking speech-language pathologist and doctoral student: Post-CVA: moderately accented; slow speech rate; vowel lengthening and raising, with schwas less reduced than in native speech; production of target alveolar flaps as alveolar stops; voicing alternations for stops; forced /r/s and light /l/s; Pre-CVA: mildly accented, with similar variations in pronunciation as post-CVA speech, but with fewer and milder mispronunciations. No motor-speech difficulties involving articulatory or breath support problems characteristic of dysarthria nor motor programming difficulties characteristic of apraxia were evident.

EC stated that the 'return' of his Hebrew accent in English (and French) post-CVA had been distressing, and that he had devoted effort to 'relearning' the AE accent along with its grammar and productive vocabulary. The present study examined the changes in EC's accent and other speech and voice characteristics by means of listener judgments in a 'sentence-perception task' and a 'segment-perception task', as well as acoustic analysis. The sentence-perception task was based on one pre-CVA and one post-CVA sentence. For the segment-perception, phrases were extracted from 15 pre-CVA and 14 post-CVA sentences. A subset of these (i.e., vowels from 9 pre-CVA sentences and from 9 post-CVA sentences) were used for acoustic analysis. The global perceptual perspective provided by the sentence-perception task, along with a more segmental-level analysis of pre-CVA vs. post-CVA differences in the segment-perception task, and acoustical analysis for more objective measures of differences, addressed the question of what differences, if any, were present in EC's pre-CVA vs. post-CVA AE pronunciation and voice. It was predicted, based on EC's self-report, that his post-CVA productions would be judged as more accented than the pre-CVA and that global changes perceived would include slower, more strained, hesitant, and more monotone speech and voice following the CVA.

Sentence-Perception Task

A sentence-perception task was designed to examine the perceived changes in global accent (Riney, Takada, & Ota, 2000) and other speech and voice characteristics of EC's post-CVA L2 English. Perceived global accent is defined as the overall perception of an accent at the sentential level, as opposed to the phonetic/phonological level, and was measured by judgments of naïve AE listeners. EC's responses to similar questions pre- vs. post-CVA were used as the source for the spoken sentence rather than asking EC to reread the same passage he had spoken pre-CVA, based on research indicating that read speech has different phonological and prosodic characteristics from spontaneous speech (Guaitella, 1999).

A possible confound in the judgment of changes in EC's accent was that the post-CVA speech was slower than the pre-CVA speech. Thus, it could be argued that slow accented-speech is perceived as more accented than is accented speech at a normal rate (see Munro & Derwing, 1998), and therefore, that the perceived changes were simply due to EC speaking slowly with the same accent he had before his CVA. Hence, comparison stimuli (at normal and slow rates) were used of speakers of Hebrew, English, and French, representing EC's three languages, as well as Spanish, an accent expected to be familiar to the judges, who resided in New York.

Method

Participants. 13 native monolingual AE listeners (10 male, 3 female; mean age = 26 years; range = 18-45 years) with no history of speech/language/hearing disorders served as judges. They were recruited via advertisements and passed a bilateral hearing screening at 20 dB at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. Of the 18 participants scheduled, 5 were excluded due to failure on the hearing screening (n = 2), failure to follow instructions (n = 1), delayed reporting of speech/language treatment (n = 1), and inability to use the computer mouse (n = 1).

Stimuli. For pre-CVA stimuli, a pre-CVA television interview with EC about his animation business was converted into sound files using Adobe® Audition 2.0 software, with a sample rate of 22 050 Hz, 16-bit resolution, on a mono channel. Post-CVA speech was transferred from EC's home via Skype™ internet technology during recorded conversations for a language-therapy project. The post-CVA recording was of language testing sessions. Skype™ technology was used, as the participant lived in California and research was conducted in New York. EC's speech output was recorded in a sound-treated booth in the Speech Production and Perception Lab at Teachers College, Columbia University. The signal entering speakers of a Dell™ Optiplex GX520 desktop computer was recorded via a Shure® (SM58) dynamic microphone attached to a Dell™ Latitude D610 laptop with a SigmaTel C-Major audio soundcard, using SoundForge® software on a mono channel with a sample rate of 22 050 Hz, 16-bit resolution. Pauses longer than 500 ms were excised from post-CVA phrases to help balance the duration differences between conditions. The pre-CVA sentence was 'Well, animation science is today the leader in rule-based animation'. The post-CVA sentence was 'Recently, there are a lot of articles about computer animation'. Both utterances had 20 syllables and were the first sentence EC used to discuss his animation company. No additional sentences were comparable in pre- and post samples; thus, a single sentence was used for this task.

Stimuli were prepared from four additional speakers for purposes of comparison: a female native speaker of Hebrew (age 46), a native speaker of Parisian French (age 24), a native speaker of Columbian Spanish (age 34), and a native speaker of American English from New York (age 26), all female. (Females were recorded because of availability of speakers with appropriate language backgrounds.) Except for the native AE speaker, all were late learners of English, with their English speech described as moderately accented by the experimenters.

The speakers of French, Hebrew, AE, and Spanish were recorded in two conditions: 1. Normal rate, simulating EC's pre-CVA recordings of the pre-CVA sentence, and 2. Slow rate, via Skype™, simulating EC's post-CVA recordings of the post-CVA sentence. The normal-rate condition was recorded using the Shure® (SM58) microphone sending the signal to the Dell™ Optiplex GX520 desktop computer with a Turtle Beach™ Riviera Sound Card, using Soundforge™ software. Durations of the sentences were 5.3 sec, 4.7 sec, 5.2 sec, 3.9 sec, 4.4 sec for EC, Hebrew, French, AE, Spanish, respectively. In the slow-rate condition, participants were instructed to speak very slowly. Durations for the post-CVA/slow-rate sentences were. 11.7 sec, 11.8 sec, 13.5 sec, 8.4 sec, 8.8 sec for EC, Hebrew, French, AE, Spanish, speakers, respectively. Files were transferred to the Dell™ computer.

Procedure. Judges were seated at the computer in a sound-attenuated booth. They were instructed to use a mouse on the EC, Hebrew, French, AE, and Spanish slow and normal-rate sound files (coded as 'Sentence A', etc.). Judges heard the stimuli via Sennheiser™ HD 280 pro headphones to the computer. Stimuli were normalised and presented at 75 dB SPL, although the participants were allowed to adjust the volume. The presentation order of rates of slow vs. normal-rate speech was counterbalanced. Using a pen-and-paper questionnaire (see https://www.surveymonkey.com/s/95FM258 for electronic version), judges rated how native- or foreign-sounding the sentences were and answered other questions about EC's speech and voice.

Results

Perceived changes in pronunciation and voice. Table 1 summarises the percent of 'post-CVA' or 'slow-speech' responses that AE listeners selected when asked which sentence was more accented, slower, more strained, more hesitant, more monotone, younger, and whether it was produced by a different speaker. All 13 AE judges reported that EC's post-CVA sentence was more accented than his pre-CVA speech. This was significantly different from chance, using the Binomial test. AE judges listed other characteristics of post-CVA speech as less rapid (100%), more strained (100%), and more hesitant (92%), and a majority (62%) perceived his voice as more monotone.

Table 1

Native American English Judges' Responses (in Percent) to Speech and Voice Characteristics of EC in Post- Cerebrovascular Accident (CVA) (Compared to Pre-CVA Condition) and Hebrew, French, English, and Spanish Speakers in Slow Condition (Compared to Normal Rate Condition)

Speaker	More accented	Slower	More strained	More hesitant	More monotone	Younger	Different speaker
EC (Post-CVA)	100	100	100	92	62	23	100
Hebrew (Slow)	77	92	85	100	54	8	100
French (Slow)	27	100	100	100	85	23	92
English (Slow)	8	100	62	92	92	7	46
Spanish (Slow)	39	92	85	100	92	8	92

No other speaker was as consistently perceived as more accented in the slow condition as was EC post-CVA. The other Hebrew speaker was judged by a majority of listeners (77%) as more accented in slow rate. However, using the Binomial test, 77% (i.e. 10 out of 13 participants) of 'more-accented' responses for the Hebrew speaker was not significantly greater than chance (50%) [$p = 0.092$].

Table 2 displays the AE judges' median ratings and ranges for the pronunciation by EC, the Hebrew, French, English, and Spanish speakers. When the judges rated EC's speech on a scale from 1-9, in which '1' was very foreign-sounding and '9' was very AE-sounding, the median accent rating for pre-CVA speech was 4 (range = 1-9). EC's post-CVA speech, in contrast, had a median rating of 1 (range = 1-2), with 11 out of the 13 judges rating it as 1. The Wilcoxon Signed Ranks Test was run on the difference scores by subject, with the difference in accentedness rating for EC's pre-CVA vs. EC post-CVA compared to the difference rating for each language normal rate vs. slow rate. Significant differences were revealed (see Appendix A).

Table 2
Native American English Judges' Accentedness Ratings of EC's Pre-Cerebrovascular Accident (CVA) vs. Post-CVA Sentences, and Hebrew, French, English, and Spanish Normal vs. Slow Rate on a Scale From 1-9, Where 1 Was 'Very Foreign Sounding' and 9 Was 'Very American-English Sounding'.

Speaker	Median rating and range for normal speech/pre-CVA	Median rating and range for slow speech/post-CVA
EC	4 (1-9)	1 (1-2)
Hebrew	2 (1-6)	1 (1-4)
French	2 (1-4)	3 (1-6)
AE	9 (7-9)	9 (6-9)
Spanish	3 (1-7)	3 (1-4)

The Wilcoxon Signed Ranks Test also confirmed that EC's post-CVA speech was rated as more accented than French, Spanish, and AE sentences in the slow-rate condition. No significant difference between Hebrew in the slow condition and EC's post-CVA ratings was found (i.e. 8 ties). EC's pre-CVA sentence, in contrast, was rated as significantly less accented than Hebrew and French normal-rate speech. The difference between Spanish and pre-CVA displayed a trend in the same direction, but was not statistically significant. The AE sentence uttered at the normal rate was rated as significantly less accented than EC's pre-CVA sentence.

Discussion

The findings from the sentence-perception task reveal that EC's speech in these sentences was perceived as more accented post-CVA than pre-CVA. EC's post-CVA speech was also perceived as slower, more strained and hesitant. Comparisons with speakers from other language backgrounds speaking at different rates suggest that slow rate did not necessarily lead to the perception of more accented speech and that EC's slower rate of speech following the CVA was not solely responsible for the perception of a stronger accent.

Segment-Perception Task

The results from the sentence perception task should be interpreted with caution because they are based on only two sentences, one pre-CVA and one post-CVA. Moreover, the sentences differed and it is possible that if one of the sentences happened to have more segments that reveal an accent, this could bias the findings. Thus, a segment perception task was performed to explore change at the phonemic/phonological level. Here pre-CVA words were matched with the same post-CVA words, extracted from 15 pre-CVA sentences and 14 post-CVA sentences, permitting a perceptual comparison of speech sounds in similar phonetic contexts.

The Hebrew inventory of approximately five vowels is smaller than the AE vowel inventory, resulting in vowel confusions when Hebrew L2 learners perceptually assimilate their L2 vowels into their native inventory (Best & Tyler, 2007). AE back vowel confusions and /i-ɪ/ and /æ-ɛ/ errors are common for Hebrew learners of English. We thus hypothesized that EC's post-CVA /ɪ/ and /æ/ production would be rated as more accented following the CVA, but that /i/, which is produced similarly in Hebrew and English, would not be rated as more accented. Vowel raising and difficulty with production of stops, /r/, /w-v/ contrasts, and interdental fricatives were also predicted based on Hebrew-accented English (Shoebottom, 2007).

Method

Participants. The participants in the segment-perception task were the same monolingual AE judges in the sentence-perception task, with two additional participants with similar language backgrounds, totalling 15 participants (11 males, 4 females; mean age = 28; range = 18-50).

Stimuli. Words from 15 sentences in the pre-CVA interview described in the sentence-perception task and from 14 sentences in the post-CVA recordings were used for the present task. Transcriptions of pre- and post-CVA conversations about EC's animation company were completed and compared for overlapping vocabulary. The same lexical items found in the pre- and post-CVA speech samples were selected as target words for the segment-perception task.

The ten target words contained ten AE vowels within stressed syllables (e.g. /i/ in 'people') or one-syllable words (e.g. /u/ in 'move'), as shown in table 3. There was no instance in which EC produced the vowel /o/ in a stressed syllable or one-syllable word in the pre-CVA recording, thus /o/ was not examined in this study. Table 3 also shows the twenty AE consonants included with matched words presented to the listeners. Because of the limited pre-CVA stimuli to match the post-CVA stimuli, the same words were reused when necessary to represent different consonants or vowels. Three-word phrases containing the target word as the second word were extracted from recordings of EC's speech pre- and post-CVA. Hesitations were excised for consistency in both pre- and post-CVA stimuli. It should be noted that although the words were matched, the use of less controlled/more spontaneous materials truer to 'real-world' speech resulted in words appearing in different phrases, thus differing in sentential focus, for example, which may affect pronunciation (Strange et al., 2007).

Table 3
American English Judges' Accentedness Ratings of EC's Pre-Cerebrovascular Accident (CVA) and Post-CVA Vowels and Consonants on a Scale From 1-9, Where 1 Was 'Very Foreign Sounding' and 9 Was 'Very American-English Sounding'. International Phonetic Alphabet (IPA) Transcription of Target Vowel Is Provided.

Vowel median ratings for correctly-identified targets			
IPA	Stimulus	Pre	Post
ɔ	sOftware	9	3
æ	thAt	8	2.5
ɑ	nOt	8	3
ʊ	wOUld	8	3
i	pEOple	7	3
ɪ	phYsics	8	4
e	animAtion	7	4
ɛ	vEry	7	4
ʌ	bUt	6	3
u	mOve	3	3

Consonant median ratings for correctly-identified targets			
IPA	Stimulus	Pre	Post
s	Software	8	2.5
ð	THat	7	2
h	Have	8	3
w	Would	8	3
l	peopLe	7.5	2.5
n	Not	8	3
p	People	8	3
d	woulD	8	3
r	veRy	8	3.5
θ	THousands	8	4
v	Very	7	3
j	Your	7	3
z	phySics	8	4
t	Time	8	4
k	physiCs	8	4
f	PHysics	8	4
g	Give	7	3.5
ʃ	animaTIOn	6.5	3
b	But	6	3
m	Move	4	2

Procedure. Participants were seated with the computer set-up described for the sentence-perception task and were first trained to identify AE speech sounds from orthographical representation. All AE vowels and consonants were produced by the experimenter, who was a native AE-speaker. The participants were then asked to isolate the vowels and consonants from the words and to pronounce them. Participants also completed a familiarisation task, in which they identified vowels of target words from pre- and post-CVA recordings of EC's not used in the actual experiment. Exclusion criteria were more than two errors on either vowels or consonants in the computer familiarisation task.

The experimental trials were then presented using Paradigm Beta 5 (2008) presentation software. The judges saw the (orthographic) phrase and keywords on the computer screen and heard the phrase stimulus simultaneously. The target grapheme in the phrase was capitalised, representing the speech sound to be judged: e.g. 'animAtion'. The participants were asked to use the computer mouse to click on the keyword representing the vowel or consonant they perceived.

The key words for vowels were ‘hEEd, hId, hAYed, hEAd, hAd, hOd, hUd, hAWed, hOOd, whO’d, hOEd’ and for consonants included ‘Geese, Deal, Key, Year, Heat, Real, THief, THem, Tea, Fee, Veal, Neat, See, Zebra, SHeep, Bee, Meet, Peel, Lean, Week’. For consonants, a subset of six key words representing consonants deemed most likely to be perceived were provided (e.g. for the stimulus ‘of THousands of’ the response choices were ‘THief, THem, Deal, Tea, Fee, Veal’). The participants then heard the stimulus again and saw a nine-point Likert scale for rating the accent. One (1) indicated ‘very foreign-sounding,’ and nine (9) ‘very AE-sounding’. Listeners were asked to try their best to ignore factors such as rate and recording-quality differences, and to focus only on the pronunciation of the target vowel or consonant. Stimuli in the pre- and post- condition were presented randomly within blocks, with each segment in each condition presented twice. A total of 120 judgments (two presentations of 20 vowels and 40 consonants in pre-CVA and post-CVA conditions) was collected from each judge.

Results

Identification. Percent-correct scores from the segment-perception task were computed for all vowels and consonants in pre- vs. post-CVA conditions and collapsed across conditions. A Wilcoxon Signed Ranks test indicated no significant differences between accuracy of identification of pre-CVA (91%) and post-CVA (90%) stimuli [$n = 15$, $T+ = 8$, $p = 0.328$]. Judges identified the vowels in the pre-CVA condition with 84% accuracy compared with 83% accuracy for the post-CVA condition, and consonants with 94% accuracy for the pre-CVA vs. 93% accuracy for the post-CVA condition, neither difference statistically significant [Vowels: $n = 15$, $T+ = 6$, $z = -0.479$, $p = 0.632$; Consonants: $n = 15$, $T+ = 7$, $z = -0.998$, $p = 0.318$].

Accentedness ratings. Table 3 depicts median ratings for correctly-identified sounds in the pre- to post-CVA condition in order of largest difference to the smallest difference from the pre- to the post-CVA condition. The post-CVA segments were judged more accented, confirmed by a Wilcoxon Signed-Ranks Test on median ratings for correctly-identified vowels [$n = 15$, $T+ = 14$, $z = -3.309$, $p = 0.001$] and consonants [$n = 15$, $T+ = 15$, $z = -3.417$, $p = 0.001$]. The range for pre-CVA ratings was from 3-9 (median = 7.5), and for post-CVA from 2.5-4 (median = 3)

Discussion

EC’s speech sounds were perceived as equally intelligible (i.e. identifiable), but more accented, following the stroke, consistent with the findings from the sentence-perception task. Although accent and intelligibility are related, there is a quasi-independent relationship between these phenomena (Derwing & Munro, 1997). For example, speakers perceived as having heavy accents or inaccurate productions may be fully intelligible in that listeners can identify an intended message or speech sound accurately (Levy & Law II, 2010).

As predicted, /æ/ and /ɪ/, which do not have direct equivalents in Hebrew, were rated as more accented post-CVA. However, /i/, which is similarly produced in the two languages also received higher ratings post- compared to pre-CVA, suggesting that listeners may have had difficulty isolating the speech sounds from their carrier phrases. In fact, the consistently stronger accent perceived for nearly all speech sounds obscured segmental changes (e.g. of /r/ and interdental fricative production) that might characterise a stronger Hebrew accent in English.

Acoustic Analysis

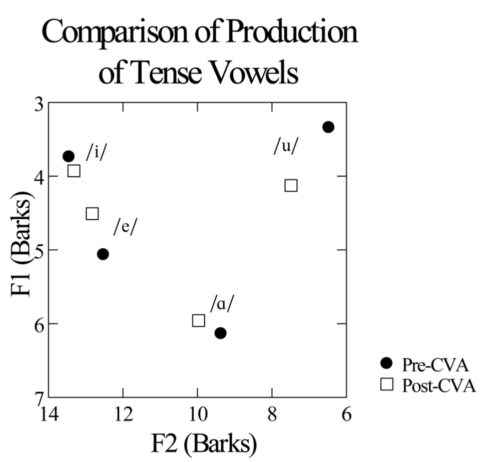
Acoustic analyses of changes in pronunciation following a CVA are rare (Coelho & Robb, 2001; Kurowski et al., 1996; Laures-Gore, Henson, Weismer, & Rambow, 2006) and are needed in order to understand such phenomena and to supplement listener judgments with more objective measures. Given the limited stimuli and scope of the present study, the changes in spectral qualities of vowels and speech rate were examined, as these were the speech characteristics the authors perceived as most salient. In addition, vowel quality changes are described as major contributors to perceived foreign accents in FAS (Dankovičová et al., 2001; Blumstein & Kurowski, 2006; Perkins et al., 2010). Furthermore, as AE has a larger vowel inventory than Hebrew, accentedness would be expected to reveal itself in vowel production. A shift toward more peripheral vowels was expected post-CVA due to the predicted slower rate and reportedly stronger Hebrew accent.

Method

The vowel stimuli judged in the segment-perception task were analyzed. These were extracted from 9 pre-CVA and 9 post-CVA sentences. Spectrographic analysis of pre-CVA and post-CVA vowels was performed using customised software in Matlab^{TM} (CVCZ by Valeriy Shafiro). The onset of the syllable with the target vowel was defined as an amplitude change indicating release of the preceding occlusion. Offset was defined as the reduction of energy in the upper formants on a spectrogram co-occurring with a decrease in waveform amplitude indicating closure beginning for the ensuing consonant. The programme calculated the temporal midpoint and displayed the first three formants for a 25 ms window around that point by means of an LPC analysis with 24 coefficients. Interjudge reliability involved measurements by two investigators and consensus with a third investigator when discrepancies arose, which occurred for three stimuli. Vowel and word durations were compared pre- and post-CVA.

Results

The top scatter plot (a) in figure 1 represents the vowels uttered by EC in the pre-CVA (black circle) and post-CVA (square) conditions in Barks, with the F2 on the X-axis and the F1 on the Y-axis. (Frequency is not perceived in a linear fashion by the human auditory system. Thus, the frequency measures of the vowels presented here were converted to a Bark scale, which more closely approximates the way in which frequency differences are perceived psychophysically [Zwicker, 1961]). A chart of EC's tense vowels is presented above the chart of his lax vowels (b). Overall, less coarticulation is evident post-CVA, particularly for lax vowels, with post-CVA vowels generally produced with formant values toward the periphery. Post-CVA production of /æ/ was more fronted (i.e. higher F2) and lowered. The vowel /ɛ/ was higher and more fronted, shifting towards /e/.



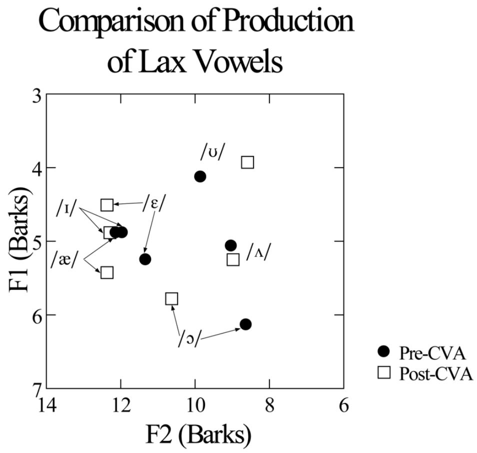


Figure 1. Scatterplot representing tense vowels (a) and lax vowels (b) uttered by EC in the pre-CVA (black circle) and post-CVA (square) conditions in Barks with the F2 on the X-axis and the F1 on the Y-axis.

Differences in vowel duration ranged from 2 to 84 ms, word duration from 39 ms to 226 ms with one case (/ɔ/) of shorter duration pre-CVA by 13 ms. Results of a Wilcoxon Signed Ranks test confirmed that the post-CVA speech was slower than the pre-CVA speech [Vowels: $n = 10$, $T+ = 7$, $z = -2.191$, $p = 0.028$; Words: $n = 10$, $T+ = 9$, $z = -2.701$, $p = 0.007$].

Discussion

Acoustic analysis was consistent with the listener judgments in indicating a change in pronunciation following EC's CVA, including a reduction in speech rate. Vowels were produced more on the periphery of vowel space, as expected, possibly, in part, as a function of the slower (Bradlow, Kraus, & Hayes, 2003) and more laboured aphasic speech. Reports of coarticulation in monolinguals with nonfluent aphasia have ranged from impaired (Weismer, Tjaden, & Kent, 1995; Katz, 2000) to relatively normal (Baum, 1998). Shifts in vowel space toward cardinal vowels (i.e. /i, ɑ, u/) have been documented in FAS (e.g. Graff-Radford, Cooper, Colsher, & Damasio, 1986; but cf. Kurowski et al., 1996), but could reflect smaller vowel system of Hebrew, as well. The relationship between the accentedness judgments and spectral properties of the vowels was inconsistent. For example, with the high-front vowels /i/ and /ɪ/, acoustic differences were minimal. The spectral differences in production for /i/ and /ɪ/ would most likely not be perceived as distinct phonological categories, given that the differences were less than 0.25 Bark (i.e. less than a 'just-noticeable difference' [Kewley-Port & Zheng, 1999]) and their durations were distinct, but the post-CVA production of both /i/ and /ɪ/ were rated as more accented than pre-CVA. The listeners may have had difficulty isolating the vowel from the rest of the utterance. However, the largest difference between pre-and post-CVA speech (6 points) was for /ɔ/, which EC produced considerably farther forward (i.e. F2 approximately 2 Barks higher) post-CVA, inconsistent with the backing of vowels in some FAS reports (e.g. Perkins et al., 2010). Lastly, the acoustic evidence supported the perception that EC's speech rate was reduced post-CVA. Acoustic analysis in FAS, in contrast, has characterised vowels as shorter in FAS than in pre-CVA (Dankovičová et al., 2001) or recovered (Perkins et al., 2010) speech.

General Discussion

The present study compared pre-CVA and post-CVA productions of sentences and segments of the L2 of a trilingual with aphasia who reported that his Hebrew accent had returned in his (L2) English. Results from this data set indicate that after his CVA, EC's L2 speech was perceived as more accented, but not less intelligible, and that his speech and voice were also perceived as more strained, hesitant, and slow following the CVA. Acoustic analysis confirmed slower speech and more peripheral vowels, consistent with several reports of speech and voice characteristics after CVAs in monolinguals with and without FAS (Kent & Rosenbek, 1983; Blumstein & Kurowski, 2006; cf. Kurowski et al., 1996).

Because EC had learned English formally, after acquiring his first-language (L1) Hebrew, and thus spoke Hebrew-accented English prior to achieving his peak pre-CVA English proficiency/pronunciation, and because his post-CVA accent was perceived as a stronger Hebrew accent, not a new accent, this case falls out of the realm of FAS (Blumstein & Kurowski, 2006). Our findings are consistent with the accounts proposed in previous studies that reported a return of a foreign accent (Seliger et al., 1992; Roth et al., 1997) following a left-hemisphere stroke, as well as Eviatar, Leikin and Ibrahim's (1999) report of a Russian-Hebrew bilingual with aphasia characterised by difficulty understanding her L2 (Hebrew) unless it was spoken with a Russian accent. These accounts suggest selective impairment of the mechanisms responsible for L2 (but not L1) phonological processing, in conjunction with impairments to other linguistic domains.

Theories of L2-speech learning agree that initial stages of learning involve processing speech sounds through native phonetic/phonological categories. L2 learners' representations are subsequently modulated by increased L2 exposure, resulting in L2 speech sounds less-often identified with sounds in learners' native phonology and new categories established for (at least some) L2 sounds (Flege, 1995; Best & Tyler, 2007). It may be argued that the modulation of equivalence classification (i.e., the linking of L1 and L2 categories) (Flege, 1995) or of assimilation (Best & Tyler, 2007) patterns that occurs with continued exposure to an L2 may be impaired following brain damage, resulting in reversion to previous patterns.

Impairments of L2 phonological processing have been associated primarily with subcortical lesions (as in Seliger et al., 1992, Roth et al., 1997, and Eviatar et al., 1999). The initial lesion of our participant involved extensive cortical regions as well as at least some subcortical structures (the basal ganglia). Evidence from neuroimaging studies of healthy bilingual speakers also suggests a role of subcortical regions in the speech production of late L2 learners, despite generally overlapping neural networks associated with L1 and L2 processing in early and late L2 learners (Frenck-Mestre, Anoton, Roth, Vaid, & Viallet, 2005).

EC's increased accent in English with his Hebrew phonology remaining less affected parallels the lexical and syntactic deficits that characterise his English more than his Hebrew, following his stroke (Goral et al., 2006). It is possible that the regions that were affected in EC's brain underlie processes responsible not only for lexical and syntactic abilities but also for speech production. This is consistent with recent theories that propose interactive networks underlying language processing rather than skill localization and language modularity (Ardila, 2010; Thompson-Schill, 2005). We suspect that many multilinguals who acquire aphasia manifest changes in accentedness but that these instances are underrepresented in the literature.

Our results demonstrate, at least for our limited data set, that the change in accent perceived by EC was measurable both by means of naïve listeners' judgments and by acoustic analysis. With the growing number of multilinguals with aphasia (Paradis, 2001) and increasing access to recording technologies, it is likely that future studies will provide further such documentation and perceptual/acoustic descriptions, which will extend knowledge of speech changes that accompany aphasia in multilinguals.

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Declaration of Interest Statement

The authors report no declarations of interest.

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Appendix A

Values of the Wilcoxon Signed Ranks Test on Difference Scores of Accentedness Rating for EC's Pre-CVA vs. EC Post-CVA Compared to Difference Scores of Rating for Each Language's Normal Rate vs. Slow Rate ('EC [pre-CVA vs post-CVA] Compared to Normal vs. Slow'), on EC's Accentedness Ratings Post-CVA Speech Compared to Slow-rate Conditions in Other Languages ('EC's Post-CVA Compared to Slow'), and on EC's Pre-CVA Sentence Compared to Normal Rate in Other Languages ('EC's pre-CVA Accent Compared to Normal'). Asterisk (*) indicates Statistical Significance.

Comparisons Tested	Speaker	Wilcoxon Values
EC (pre-CVA vs. post-CVA) compared to normal vs. slow	Hebrew	n = 13, T- = 10, z = -2.429, p = 0.015*
	French	n = 13, T- = 12, z = -3.066, p = 0.002*
	AE	n = 13, T- = 10, z = -2.774, p = 0.006*
	Spanish	n = 11, T- = 9, z = -2.692, p = 0.007*
EC's pre-CVA accent compared to normal	Hebrew	n = 13, T- = 10, z = -2.315, p = 0.021*
	French	n = 13, T- = 11, z = -2.947, p = 0.003*
	AE	n = 13, T+ = 11, z = -2.950, p = 0.003*
	Spanish	n = 12, T- = 6, z = -1.809, p = 0.07
EC's post-CVA accent compared to slow	Hebrew	n = 13, T+ = 4, z = -1.414, p = 0.157
	French	n = 13, T+ = 10, z = -2.831, p = 0.005*
	AE	n = 13, T+ = 13, z = -3.247, p = 0.001*
	Spanish	n = 12, T+ = 11, z = -2.971, p = 0.003*