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Inter-language interference in VOT production by L2-dominant bilinguals: Asymmetries in phonetic code-switching

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Abstract

Speech production research has demonstrated that the first language (L1) often interferes with production in bilinguals' second language (L2), but it has been suggested that bilinguals who are L2-dominant are the most likely to suppress this L1-interference. While prolonged contextual changes in bilinguals' language use (e.g., stays overseas) are known to result in L1 and L2 phonetic shifts, code-switching provides the unique opportunity of observing the immediate phonetic effects of L1-L2 interaction. We measured the voice onset times (VOTs) of Greek–English bilinguals' productions of /b, d, p, t/ in initial and medial contexts, first in either a Greek or English unilingual mode, and in a later session when they produced the same target pseudowords as a code-switch from the opposing language. Compared to a unilingual mode, all English stops produced as code-switches from Greek, regardless of context, had more Greek-like VOTs. In contrast, Greek stops showed no shift toward English VOTs, with the exception of medial voiced stops. Under the specifically interlanguage condition of code-switching we have demonstrated a pervasive influence of the L1 even in L2-dominant individuals.

Keywords

bilingual; L2 dominant; Greek; Australian English; speech production; voice onset time; code-switching

0. Introduction

Bilingualism is defined as the regular use of two languages (Grosjean, 1982). Regardless of their proficiency (e.g., fluent vs. learner), sequence of language learning (e.g., sequential vs. simultaneous), or age of acquisition (e.g., early vs. late), bilingual speakers face the challenge of accommodating two languages. One of the most interesting and debated facets of bilingualism is whether and how these two languages interact within an individual language user (Appel & Muysken, 1987; Baetens Beardsmore, 1986; Romaine, 1989).

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Although this question has been investigated for many years, speech production research has yielded mixed results regarding how this interlanguage interaction influences the phonetic details of a bilingual's speech in the L1 and L2 (Caramazza, Yeni-Komshian, Zurif, & Carbone, 1973; Flege, 1991, 2002; Kang & Guion, 2006; Mack, 1989; MacLeod & Stoel-Gammon, 2008; Magloire & Green, 1999; Sundara, Polka, & Baum, 2006; Williams, 1977). In the present report, we will use code-switching as an innovative tool to investigate the occurrence and direction of any phonetic interference resulting from interaction between bilinguals' two languages (henceforth interlanguage interaction).

Influence between a bilingual's L1 and L2 may result from one of four possible interlanguage interactions. The first and most obvious possibility is that the earlier-acquired L1 influences production of the L2. It is common for bilinguals to speak their L2 with a detectable foreign accent, that is, produce speech that is detectably different from that of native speakers of the language. Substantial evidence suggests that the extent of the differences between bilingual production of L1 and L2 phones from those of monolinguals depends on the age at which each language is acquired (Flege, 1991; Flege & Eefting, 1987a; Flege & Liu, 2001; Flege, Munro, & MacKay, 1995). This difference occurs because acquiring languages sequentially necessarily means that the L2 is learned through the 'filter' of the L1. The resulting influence of the L1 on the L2 is termed 'interference' (Flege, 1987; Flege & Davidian, 1984; Flege & Port, 1981). Numerous studies have demonstrated that the effects of this interference persist in L2 production (Caramazza et al., 1973; Flege, 1991; Flege & Eefting, 1987a) and also perception (Pallier, Colome, & Sebastián-Gallés, 2001; Sebastián-Gallés & Soto-Faraco, 1999), even after many years of continued L2 use. For instance, early Spanish–English bilinguals, who had either been born in the United States or moved there shortly after birth, were nonetheless constrained as adults by the short-lag voice onset times (VOTs) of Spanish (their L1), in that they produced shorter VOT values for English /p, t, k/ than age-matched English monolinguals (Flege & Eefting, 1987a). These findings are consistent with a unidirectional L1-influence on the L2.

A second possibility for interlanguage interaction is that learning an L2 may also eventually result in changes in production of the L1, compared to how the L1 was produced prior to L2 learning (in addition to interference from the L1 on the L2). Such an L2 influence on the L1 could not be accounted for by interference as the L1 was obviously not acquired through the filter of the L2. Rather, by this account the L1 and L2 would presumably influence one another as the L2 is acquired and used, resulting in bidirectional interlanguage interaction. Support for this bidirectional account is found, for example, in evidence that Dutch–English bilinguals were constrained by the short-lag VOTs of Dutch voiceless stops, and produced L2-English /t/ with shorter VOT (60 ms) than native speakers of English (90 ms). Moreover, those bilinguals with the best English accents had more English-like VOTs (longer than bilinguals with poor English accents), and also produced Dutch /t/ with even shorter VOTs than other Dutch speakers (Flege & Eefting, 1987b). That is, learning their L2 seemed to have resulted in polarisation of the L1 and L2 phones in these speakers with good L2 accents, and this bidirectional interaction lead to productions that differed from native speakers of both languages.

The extent of this L1-L2 bidirectional interaction may depend on the amount of L1 experience at the onset of L2-learning. For example, English–French sequential bilinguals (who learned French by 10 years-of-age) were constrained by the long-lag VOTs of English (their L1) and produced French stops with longer VOTs (more English-accented) than simultaneous bilinguals (exposed to French and English from birth) (Fowler, Sramko, Ostry, Rowland, & Hallé, 2008). Moreover, the simultaneous bilinguals' French VOTs were longer than French–English sequential bilinguals (who learned English by 5 years-of-age), whose VOTs were, in turn, longer than those of monolingual French speakers. An analogous effect was observed for English stops: The French–English bilinguals were constrained by the short-lag VOTs of French (their L1), and produced shorter English VOTs than simultaneous bilingual speakers, whose VOTs were shorter than English–French bilinguals who, in turn, fell short of the long-lag VOTs of monolingual English speakers (Fowler et al., 2008). These findings suggest that not only do the L1 and L2 influence one another, but also that the bilinguals' pattern of acquisition contributes to the direction and magnitude interlanguage interaction.

It is important to note that previous studies investigated the speech of talkers in stable language environments, that is, in situations where interaction between the two languages was unlikely to occur, so it would be expected that their language systems are in a relatively stable state. It is also interesting to consider whether VOT productions vary when the language environment changes. Sancier and Fowler (1997) measured the VOTs of a Portuguese–English late bilingual (who learned English at 15 years-of-age) who annually spent several months in the United States and several months in her native Brazil. For the duration of her stay in the United States she mainly spoke English, and upon her return to Brazil, her Portuguese (L1) voiceless stops were rated as more American-sounding than prior to her travel. Acoustic measurements confirmed that the typically short-lag VOTs of her Portuguese voiceless stops had drifted by 5-6 ms toward the longer VOT values of English. Upon return to the US from Brazil, the speaker's voiceless stop VOTs in both languages had shifted just as much, this time toward the shorter values of Portuguese. In other words, the speaker experienced *gestural drift* in both languages, toward the norms of the language environment, demonstrating that temporary language-context-dependent changes occur at a detailed phonetic level in a bilingual speaker's L1 *and* L2 VOT productions.

To summarise thus far, we have reviewed two possibilities of interlanguage interaction: unidirectional L1-influence on the L2 and bidirectional L1-L2 interaction. A third possible outcome is that the later-acquired L2, if it becomes the dominant language, may be freed of L1 interference and will instead influence the L1. Flege, MacKay and Piske (2002) studied early Italian–English bilinguals who after many years of continued L2 usage had become dominant in their L2 (English) and did not have detectable foreign accents (based on the ratings of native English listeners). Based on these observations, those authors suggested that L2-dominant bilinguals, because of their fluency in the L2, may be the most likely to suppress L1 phonetic interference on L2 production. In the Flege et al. (2002) account, language dominance is hypothesised to be the crucial factor that determines which language (L1 *or* L2) will influence the other, nondominant language. Past results (Flege, 1991; Flege & Eefting, 1987a; Flege & Liu, 2001; Flege et al., 1995) can be reinterpreted from this viewpoint, that it is not the L1 filter per se that interferes with L2 production, but rather it is the bilingual's L1-dominance. That is, it may be that the bilingual's dominant language remains unaffected, whether it is L1 or L2, and exerts a unidirectional influence on production in the nondominant one.

The fourth and final possibility of interlanguage organisation is that there is no interaction and that the L1 and L2 do not influence one another. This account has been supported by those rare studies that have reported that bilinguals produced speech equal to that of monolinguals of each language on some measure of phonetic performance. For example, Magloire and Green (1999) reported cases of Spanish–English bilinguals who produced Spanish (L1) and English (L2) /ba, pa/ with monolingual-like VOTs even at fast and very fast speaking rates. Also, in past work, we identified a large population of L2-dominant Greek–English early sequential bilinguals (who learned English by 6 years-of-age) in Australia, and examined their speech production in unilingual mode (Greek or English), meaning that all contact, instructions, and feedback occurred in only one language for a given speaker. Under this convincing *unilingual-mode* manipulation, the bilinguals produced monolingual-like VOTs for both Greek (which contrasts stops with lead vs. short-lag VOT) and English (which contrasts stops with short vs. long lag) bilabial and coronal stops /b, d, p, t/ when occurring in initial position. Modest differences from monolinguals emerged in some of the English (L2), but not Greek (L1), stops in phonetically complex medial contexts (Antoniou, Best, Tyler, & Kroos, 2010). These findings are evidence that bilingual speakers can, in unilingual conditions, produce monolingual-like L1 and L2 speech, suggesting no interlanguage interaction.

Thus far, we have reviewed evidence supporting all four possible outcomes of interlanguage interaction. In trying to account for such seemingly contradictory findings, Flege devised the Speech Learning Model (SLM). According to SLM (Flege, 1995, 1999, 2002; Flege, Schirru, & MacKay, 2003), bilinguals will differ from monolinguals of either language because the phonetic categories used to produce and perceive *both* the L1 and L2 reside in a common acoustic-phonetic space, and will inevitably influence one another. SLM posits that L2-learning may systematically restructure the organisation of the L1. As such, SLM accounts for findings that the L1 exerts unidirectional influence on the L2, especially as the age of learning of the L2 increases, and provides an even more complete explanation for bidirectional interlanguage interaction. However, SLM offers no explanation as to how the L2 can be produced without a foreign accent, and therefore cannot account for findings suggesting unidirectional L2-influence on the L1 (Flege et al., 2002) or for findings that suggest little to no interlanguage interaction (Antoniou et al., 2010; Magloire & Green, 1999). To account for findings that L2-dominant early bilinguals produce monolingual-like speech in the L1 (e.g., Antoniou et al., 2010) or L2 (e.g., Flege et al., 2002), SLM would need to be revised (see Flege et al., 2002, p. 593).

In cross-language *perception* research, SLM has often been compared with the Perceptual Assimilation Model (PAM; Best, 1993, 1994, 1995). While PAM does not explicitly address speech production, some aspects of the PAM extension to L2 perceptual learning, PAM-L2 (Best & Tyler, 2007), are useful here. PAM-L2 posits that, during L2 learning, reattunement to the new language may result in new L2 phonetic and phonological categories being established for certain types of perceived L1-L2 similarities, but not for others. But whereas PAM-L2 deals with perception, the present paper is concerned with examining the effects of this L2 attunement on bilinguals' production. It is possible to extend the principles of PAM-L2 to production as, according to Articulatory Phonology (Browman & Goldstein, 1992, 1993, 2000), that PAM uses as its phonological framework, speech perception and production are linked by a common phonological currency (Goldstein & Fowler, 2003): The phonological forms that users produce and perceive must be the same, specifically, they produce and perceive articulatory gestures. By acquiring an L2, learners are exposed to a new set of articulatory gestures, including new phasing relations and patterns of coordination between these gestures. In time they may learn to produce some of the gestural constellations of the L2. If we assume that fluent bilinguals develop language-specific phonetic categories that are linked at the phonological level in production, it may be possible to explain the four possibilities of L1-L2 interaction. For example, from a PAM-L2 *production* perspective, the reason why Sancier and Fowler's (1997) late Brazilian-Portuguese–English bilingual produced distinct VOTs in the L1 and L2 but still showed an influence of the language environment in both languages toward the most recent language immersion environment is because the phonetically distinct English [p^h] and Portuguese [p] were both identified *perceptually* as belonging to the higher level, abstract phonological category /p/.

PAM-L2 also offers explanations for successful L2 perceptual learning. It places great importance on patterns of language acquisition and use in explaining L2 speech perception.

Applied to production, PAM-L2's approach may help to explain the disparate findings on interlanguage interaction in past production studies. For instance, the Greek–English bilinguals tested by Antoniou et al. (2010) were exposed to the L1 (Greek) from birth, and later acquired the L2, usually when they began spending much time outside of the home (e.g., when they first attended preschool or kindergarten). Because they were living in a predominantly English-speaking environment, they were immersed in that L2, and it quickly became their dominant language. The communicative pressure associated with keeping up with their monolingual-speaking peers, along with the challenge of managing a rapidly expanding L2 vocabulary, resulted in perceptual reattunement to the L2; they attuned to the contrastive segments of the L2, setting the stage for the formation of language-specific phonetic categories in production as well. Importantly, this reattunement would have occurred as the bilinguals were still in the process of acquiring (new words in) their L1.

Although consideration of phonological and phonetic levels and the patterns of bilinguals' language acquisition and use might help account for the four possibilities of interlanguage interaction, PAM-L2 would still require considerable extension to apply to production. Furthermore, although PAM uses Articulatory Phonology as the framework for linking production and perception because they use the same information (coordinated articulatory gestures), it is still not clear exactly how the mechanisms of perception and production are linked.

A coherent account of bilingual interlanguage behaviour, although not directly concerned with the phonetic effects on speech production, is offered by the Language Mode framework (Grosjean, 1982, 1989, 1998, 2001, 2008), which posits that bilinguals move along a language-activation continuum ranging from unilingual[1] to bilingual. A unilingual mode is used when interacting with a monolingual speaker or in other formal single-language situations, where the other language is not used and is temporarily deactivated, although never completely. An appropriate stimulus, such as printed text that unequivocally specifies the temporarily deactivated language will reactivate that language, placing the bilingual in a bilingual mode, in which the bilingual switches between languages. In this instance, both languages are activated but one is used for language processing and, as a result, is more active than the other (Grosjean, 2001). The Language Mode framework offers an explanation for findings suggesting a lack of interlanguage interaction (Antoniou et al., 2010; Magloire & Green, 1999), as the bilinguals were in a unilingual mode at the time of recording, suppressing the influence of the temporarily deactivated language. The Language Mode framework is also compatible with the bidirectional interaction observed by Sancier and Fowler (1997), as the framework places strong emphasis on the linguistic setting. In other words, some "bleeding" (incomplete suppression of either language) may occur between the L1 and L2, what is referred to as a base-language effect.

The Language Mode framework demands that in order to truly test whether there are differences between monolinguals and bilinguals, it is necessary to force the two languages to interact by placing bilinguals in a situation where they need to combine their use of both languages, rather than examining production in one language only. Therefore, in order to test the four possibilities of interlanguage interaction that exist in the literature, we investigated such context-dependent changes in bilingual speakers' productions, similar to that reported by Sancier and Fowler (1997), but within an immediate timeframe in the laboratory, by systematically manipulating the language context. Specifically, we examined the phonetic effects of *code-switching* on bilinguals' L1 and L2 speech, which we employed

[1]Grosjean (2001, 2008) refers to this condition as "monolingual" but we find the term misleading, and it is inconsistent with Grosjean's own stance that "the bilingual is not two monolinguals in the one person" (1989), therefore we've adopted the new and clearer term *unilingual*.

as a sensitive online test of L1-L2 phonetic interaction. For our purposes, we operationally defined code-switching as a within-utterance shift from the base language of the established conversational context, to produce a within-sentence target word in their other, out-of-context language (Grosjean, 1982, 2008). We note, however, that there is no consensus in the literature as to what constitutes a code-switch in a broader sense (see Clyne, 1987; McClure, 1981; Pfaff, 1979; Romaine, 1989).

Although higher levels of language use have been fairly extensively investigated with code-switching, its effects on phonetic realisation during speech production have received little attention. For instance, code-switching has received considerable attention from linguists, who have investigated its grammatical aspects (Li, 1996; Myers-Scotton, 1997; Sankoff & Poplack, 1981), including syntactic, morphological and lexical constraints on code-switching (Berk-Seligson, 1986; Clyne, 1987; Poplack, 1988), and the processing costs of code-switching (Grosjean, 1988; Jared & Kroll, 2001; Macnamara, 1967; Macnamara & Kushnir, 1971), as well as the social contexts within which code-switching occurs (Timm, 1993; Treffers-Daller, 1997; Vihman, 1985). Specifically, when perceiving sentences containing code-switches, bilinguals show a base-language effect. That is, the main language of the communication affects the other ‘guest language’ (Grosjean, 1988), the processing of the sentence is slightly inhibited (Altarriba, Kroll, Sholl, & Rayner, 1996), comprehension in the nontarget language is delayed (Li, 1996), and passages containing code-switches are read more slowly than single-language passages (Kolers, 1966; Macnamara & Kushnir, 1971). Given that code-switching at higher levels show an interlanguage interaction, it would seem likely that code-switching should have an effect at the phonetic level as well.

Somewhat surprisingly, in one of the few code-switching production studies conducted, French–English bilinguals failed to show any L1-interference, relative to their own productions in unilingual English mode, when they code-switched within French base-language sentences (i.e., short-lag VOT voiceless stops) to produce the long-lag VOT English voiceless stops /p, t, k/ in word-initial position (Grosjean & Miller, 1994). These findings are compatible with the account suggesting there is no interlanguage interaction in fluent bilinguals. However, as the bilinguals were not compared to English monolingual speakers, it is not possible to verify that their unilingual-mode productions of code-switched English stops were not *already different* from those of monolingual English speakers. Adding to these difficulties in interpreting their result, Grosjean and Miller (1994) did not describe the language dominance of their bilingual participants, who also differed fairly widely in the age at which they had acquired their L2-English (some in primary school, others in secondary school), both of which are important factors in L2 speech production accuracy, especially with respect to L1-inteference on L2 production (Flege et al., 2006; Flege, Frieda, & Nozawa, 1997; Flege et al., 1995; Flege et al., 2003; Flege, Yeni-Komshian, & Liu, 1999). Thus, we cannot have a complete understanding of the effects of code-switching on speech production without examining code-switching in bilingual speakers who would otherwise show little or no interlanguage interaction in their productions.

By investigating L2-dominant, early bilinguals, we were able to test whether code-switching gives rise to L1-L2 phonetic interaction in bilingual speakers who had already been observed to produce monolingual-like speech in both languages when operating within a unilingual language mode, with the caveat that in the phonetically more complex medial positions, modest L1 interference was observed for some of the English (L2) stops (Antoniou et al., 2010). Code-switching should also be more likely than a unilingual speaking mode to reveal any interaction between the two languages in the phonetic realisation of the targets. Within-utterance phonetic code-switching is also potentially more

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sensitive to both L1 and L2 influences (and asymmetries in direction), as well as to gestural drift, but in much shorter time frames than Fowler and colleagues have examined, and in a context that is quite similar to the naturally-occurring code-switching seen in bilinguals. If we observe interlingual influences in the speech of fluent bilingual speakers by instructing them to switch languages mid-utterance, this would have further theoretical implications for phonological organisation in L2-dominant bilingual speakers. That is, the code-switching manipulation may possibly reveal that even fluent L2-dominant bilingual speakers who otherwise produce monolingual-like VOTs are not immune to L1-L2 interaction when rapidly switching from one language to the other within the same utterance. If so, this would suggest that past work, which has investigated bilinguals' productions in stable language situations, has provided an incomplete account of bilingual interlanguage interaction. If L1-L2 interaction effects are not observed, this would suggest that bilinguals suppress interlanguage phonetic influences, even when rapidly switching between languages, consistent with the view that there is little or no interlanguage interaction even when bilinguals switch languages.

We predicted, however, that the bilinguals would show a similar, and presumably stronger, asymmetry in their L1-L2 interaction when code-switching, as observed in a unilingual mode. If interlanguage effects are observed in the bilinguals' code-switches, this would mean that L1 and L2 phones are perceived as similar at a higher, more abstract level. Based on Antoniou et al.'s (2010) observations of (albeit modest) L1-interference in the medial positions under unilingual speaking modes, we also expected the effects of the L1-L2 interaction in code-switched utterances to be more prevalent for stop-voicing in medial contexts than in initial position. Additionally, the medial contexts warrant investigation in their own right as most cross-language phonetic research has only investigated initial contexts (see Strange, 1995).

We selected VOT in the production of stop voicing distinctions as our measure of phonetic interference, as it is the measure that has been reported in the great majority of past research. Thus, this measure allows for direct within-subjects comparison with our own work (Antoniou et al., 2010), and cross-subject comparisons with other directly relevant research (Fowler et al., 2008; Grosjean & Miller, 1994; Sancier & Fowler, 1997). In addition, like French and Portuguese as compared to English, Greek and English also differ in the phonetic settings they use to make distinctions along the VOT continuum: Greek voiced stops are produced with voicing lead (prevoicing, or negative VOT values) and voiceless stops are short-lag unaspirated (small but positive VOT values) (Botinis, Fourakis, & Prinou, 2000), whereas English voiced stops are short-lag unaspirated and voiceless stops are long-lag aspirated (large positive VOTs), just as in other more often studied varieties of English (Cox & Palethorpe, 2007).

Importantly for the current experiment, Greek and English differ not only in their phonetic settings for stop-voicing distinctions, but in their orthographies as well. In addition to the difference in English and Greek alphabets, the Greek voiced stops are represented not by single letters as in English, but by digraphs (b: μπ = mp, d: ντ = nt), a remnant of their origin from Classical Greek sequences of nasal + voiceless stop (Newton, 1972). This difference in orthography in the printed target sentences should indicate unequivocally to the speakers exactly where a code-switch is to occur, thus serving as a constant reminder of the switch in language for the target item. Only Greek–English bilinguals who are competent readers in both languages were recruited. This was to ensure that the phonological code for the given language was automatically induced in both directions by the differing orthographies.

It is important to note that while Greek voiced stops in initial-position are invariably prevoiced, there is great variability in the realisation of Greek voiced stops in word-medial contexts, where some preceding nasality may or may not be evident depending on the speaker and dialect (Newton, 1961; Viechnicki, 1996). For this reason, we first investigated initial-position stops (Experiment 1) as they provide the simplest and most clear-cut VOT differences between Greek and English. This also allowed us to compare our findings with the most relevant past studies, before investigating the phonetically more complex medial-position post-vocalic (Experiment 2a) and post-nasal contexts (Experiment 2b). The phonetically more complex medial positions allow us to check for the robustness of our findings across phonetic contexts, as well as permitting us to probe the effects of the differences between Greek and Australian-English phonetic realisations of voiced stops (for a detailed discussion see Antoniou et al., 2010).

In an effort to reduce inter-participant variability, we invited the same groups of bilinguals from Antoniou et al. (2010) to participate in the code-switching experiment. The group that had produced Greek stops in a unilingual Greek language mode in the original study (Antoniou et al., 2010) now produced those same Greek stops again, but as a code switch from an English carrier sentence. Similarly, those who had produced English stops in the original study now produced the same English stops again, but in a Greek carrier sentence. As such we were able to compare VOTs for the same stops by the same group of speakers in unlingual versus code-switching contexts.

To summarise, by asking bilinguals to code-switch, our study offers a sensitive test that will differentiate among the four possible outcomes of L1-L2 interaction:

1. Unidirectional L1-influence on the L2 (Caramazza et al., 1973). The L1 will interfere with productions in the L2, in that L2 English voiced stops will be produced with longer voicing lead and voiceless stops with shorter lag (more Greek-like VOTs). This L1-interference would be expected to be present despite years of L2 experience, consistent with the persistent L1-effects on L2- perception reported by Sebastián-Gallés and colleagues (Pallier et al., 2001; Sebastián-Gallés & Soto-Faraco, 1999; Sebastián-Gallés, Echeverría, & Bosch, 2005). Furthermore, this L1-interference should be present even in bilinguals who are L2-dominant, compatible with Antoniou et al.'s (2010) stop VOT findings in the medial contexts.
2. Bidirectional L1-L2 interaction. The L1 and L2 will influence one another, resulting in speech that differs from that produced in unilingual mode for both the L1 and L2. Such an account is compatible with SLM's notion of a common acoustic-phonetic space (Flege, 1995), as well as the symmetrical VOT changes observed in the gestural drift studies (Fowler et al., 2008; Sancier & Fowler, 1997).
3. Unidirectional L2-influence on the L1 (Flege et al., 2002). Because the present sample of bilinguals is L2-dominant, this account predicts that they will suppress the influence of the L1, and their L2 productions will be free of L1-interference (Flege et al., 2002). By extension, we expect that the dominant L2 (English) will influence the code-switched productions in the nondominant L1 (Greek), making them more English-like (voiced stops: shorter voicing lead, voiceless stops: longer lag VOT).
4. No L1-L2 interaction. This outcome would be consistent with the account of Grosjean and Miller (1994) who argue that bilinguals switch languages completely, free of interlanguage phonetic interference. By this account, the bilinguals will switch languages and the L1 and L2 will be unaffected by the surrounding language context or the code-switch.

1. Experiment 1: Initial position stops

1.1. Method

1.1.1. Participants—Two groups of eight bilinguals (Greek targets in English mode group M_{AGE} = 31.2 years; English targets in Greek mode group M_{AGE} = 26.1 years; four males and females per group) were recruited in a previous production study and were brought back to the lab for a second recording session. The earlier recordings of these same 16 bilinguals in unilingual Greek and English modes have been reported previously (Antoniou et al., 2010) and were used for baseline comparisons in the present study. The two groups were recruited from the same population, the Greek-English Australian community in Sydney, and strict selection criteria were employed to ensure that they did not differ in the ages at which they acquired their L1 Greek (exposed from birth), their L2 English (English targets group: 3.6 years; Greek targets group: 3.4 years), nor in their level of mastery of Greek (mean self ratings of 3.5 and 4.0 out of 5, respectively), and mastery of English (both groups reported mean self ratings of 5 out of 5). All continued to use both Greek and English in their everyday lives. Participants were financially compensated for their time.

1.1.2. Stimuli—Speakers produced bilabial /p, b/ and coronal /t, d/ stop consonants in word-initial (Ca) context. Targets were embedded in Greek or English phonetically matched carrier phrases, *say* /Ca/ *again*, and in Greek, *λέει*/Ca/ *άλλο* ([lei /Ca/ alo]).

When the bilinguals were instructed to code-switch in the second recording session, the English targets were embedded in Greek carrier phrases or Greek targets in English carrier phrases. For example, the voiceless bilabial stop was presented as a code-switch in *say* **πα** *again* (code-switch Greek) and *λέει* pa *άλλο* (code-switch English).

1.1.3. Procedure—All speakers who had participated in the unilingual-mode recordings reported in Antoniou et al. (2010) returned 3-6 months later for a second, code-switch recording session. For recording session 2, bilinguals produced the identical (i.e., one group produced Greek, the other English) targets as in recording session 1, but the language context (all contact, instructions, forms, carrier phrases and feedback) was in the opposite language to that used in their first recording session. Thus, in session 2 the production of the target required a within-utterance code-switch. Participants were instructed that the onscreen text would require them to switch languages to produce the target, and they were familiarised before recording began with the presentation of the printed targets in the code-switched orthography, embedded in carrier phrases from the other language/orthography (e.g., for a Greek target in the English code-switch condition, *say* **πα** *again*; for an English target in the Greek code-switch condition: *λέει* **pa** *άλλο*). The experimenter was the same simultaneous bilingual who conducted the initial recordings in Antoniou et al. (2010). Thus, each participant knew that the experimenter could speak both English and Greek. However, the opposite language context of the present series of experiments was clearly communicated, and strictly adhered to, during the code-switch recording session.

The targets in carrier sentences were presented on a computer monitor in quasirandom order. To minimise contrastive hyperarticulation, stop-voicing minimal pairs that share the same place of articulation were not presented in consecutive trials (e.g., /pa/ vs. /ba/). Stimulus presentation was controlled by Opa 1.0 stimulus presentation software developed at MARCS Auditory Laboratories for this purpose. Trials containing coughs, stutters or speech errors were rejected and repeated later in the task. Four correct utterances were recorded for each target. This resulted in a total of 80 recorded utterances per bilingual speaker: For initial position stops in Experiment 1, 16 utterances were recorded (2 places of articulation × 2 voicing categories × 4 utterances), whereas in Experiments 2a and 2b, 32 utterances were recorded (i.e., the number of recordings for the medial positions was doubled because separate recordings were made with stress on the first syllable and for stress on the second syllable). Note that all stops reported in Experiments 1, 2a and 2b were elicited quasirandomly in a single, code-switch recording session, but have been conceptually separated into three experiments for clarity of presentation.

Speech was recorded digitally to computer (16 bit, 44.1 kHz) using a Shure SM10A headset cardioid microphone and an EDIROL UA-25 USB audio interface. The recordings took place in an anechoic chamber at MARCS Auditory Laboratories (Xu, Buchholz, & Fricke, 2005). The recordings were segmented and labeled using Praat (Boersma & Weenink, 2001). Markers were placed at the beginning of the closure phase of the stop (defined in the acoustic signal as the point where a substantial loss in energy of the formants of the preceding vowel was observed), at the moment of consonantal release (where a release burst or spike was visible in the oscillogram), and at the end of the burst at the onset of the vowel (defined as the first periodic fluctuation following the burst). If periodic pitch pulses were absent in the waveform immediately before the release burst, the stop was considered voiceless and positive VOT was reported, whereas if pitch pulses were present immediately before the release, the stop was considered prevoiced and negative VOT was reported (see illustrative oscillograms and spectrograms of Greek voiceless and voiced stops in Figure 1).[2]

1.2. Results

For stops in word-intial position (16 targets per speaker), we conducted a 2 × (2 × 2 × 2) analysis of variance (ANOVA) with the between-subjects factor of target language (Greek vs. English), and within-subjects factors of recording session (unilingual mode vs. code-switch), target voicing (voiced vs. voiceless), and place (bilabial vs. coronal). That is, we compared the VOTs of Greek targets produced by bilinguals in a unilingual-Greek mode (from Antoniou et al., 2010) with their own productions of the same Greek targets when code-switching from within an English speaking context (the code-switching condition for the current study), and the VOTs of English targets by another group of bilinguals in a unilingual-English mode (Antoniou et al., 2010) with their own productions of the same English targets when code-switching from within a Greek speaking context in the current study (see cell means and standard deviations in Table 1).

All significant effects and interactions are listed in Table 2, but we will focus on those that involve the factors of most central interest to the present paper: target language and recording session. A significant main effect of target language confirmed the expected language-specific VOT differences between Greek (negative mean VOT due to long lead of voiced stops) and English (positive mean VOT due to long lag of voiceless stops) (M_{GREEK} = -48.0 ms; $M_{ENGLISH}$ = 28.3 ms). A significant Target Language × Voicing interaction showed that the overall VOT difference between voiced and voiceless stops was greater in Greek than in English (Greek: M_{VOICED} = -115.0 ms, $M_{VOICELESS}$ = 19.1 ms; English: M_{VOICED} = -18.6 ms, $M_{VOICELESS}$ = 79.6 ms).

Importantly, a significant Target Language × Recording Session interaction revealed that the mean VOT shift between the unilingual mode and code-switched recordings, collapsed across voicing, was greater for the English targets than the Greek targets ($Mdiff_{GREEK}$ = -10.2 ms; $Mdiff_{ENGLISH}$ = 27.8 ms). This Target Language × Recording Session interaction is shown in Figure 2. Simple effects tests on this interaction showed that English VOTs became more Greek-like (i.e., voiced stops had more lead VOT, and voiceless stops had shorter lag) in the code-switch recordings, $F(1, 14) = 11.6$, $p = .004$, whereas Greek VOTs

[2]Note that lead VOTs are bounded by closure duration, and thus, changes in lead may reflect changes in closure duration in code-switch versus unilingual mode recordings.

were unaffected by recording session. Any effects or interactions not listed in Table 2 were not significant.

1.3. Discussion

The bilinguals' productions overall were consistent with the known VOT differences between Greek and English. As discussed in Antoniou et al. (2010), when in unilingual mode, the bilinguals produced the Greek voiced stops with voicing lead and voiceless stops with short-lag VOT, and the English voiced stops either with slight prevoicing (/ba/) or short-lag (/da/) and both voiceless stops with long-lag VOT. These findings support the existence of separate language-specific phonetic categories, that is, Greek [b, d, p, t] versus English [p, t, p^h, t^h], for the bilingual groups, as proposed by PAM-L2 (Best & Tyler, 2007) for perception, but now extended to production.

We employed code-switching as a test of L1-L2 phonetic interaction and to test the four possible outcomes from the existing literature regarding the direction of this interaction. Code-switching affected the bilinguals' productions of initial English stops, whereas the initial Greek stops were unaffected. When code-switching from Greek (their L1) mode so as to produce the English targets (their L2), the bilinguals produced the English voiced stops with longer voicing lead, and produced the voiceless stops with shorter lag, that is, with more Greek-like (L1-like) VOTs for both voicing categories. This occurred even though English, the bilinguals' second language, is their dominant language.

These findings demonstrate that the L1 interferes with the L2 in production, even following years of L2-dominant experience in an L2-immersion environment. An important and novel contribution of our study is that this L1-interference was induced by our deliberate code-switching manipulation. In a previous set of experiments, we demonstrated that when in unilingual mode, the bilinguals' initial-position stop VOTs were indistinguishable from those of monolingual speakers in both languages (Antoniou et al., 2010). In the present study, we have demonstrated that codeswitching may result in unidirectional L1-interference on production of L2 segments in this same position, analogous to the perceptual findings of persisting L1 influence on perception in the L2, by Sebastián-Gallés and colleagues (Pallier et al., 2001; Sebastián-Gallés & Soto-Faraco, 1999; Sebastián-Gallés et al., 2005). Importantly, we observed L1-interference on production of the L2, despite our bilinguals' L2- dominance.

The results of this study provide the first clear evidence that code-switching can have an effect on the phonetic realisation of a bilinguals' production of speech. This is consistent with past research on higher levels of language use (e.g., lexical or grammatical constraints), which has found that code-switching shows a base language effect, or processing cost (Altarriba et al., 1996; Grosjean, 1988; Kolers, 1966; Li, 1996; Macnamara & Kushnir, 1971). We have demonstrated that code-switching shows an analogous base language (L1) effect at the phonetic level in speech production as well, and thus is a sensitive test of L1-L2 phonetic interference as well as asymmetries in direction.

These findings make an important contribution by supplementing those of Flege et al. (2002) who reported that L2-dominant bilinguals' productions of L2 sentences were free of L1-interference, as rated by native-speaking judges. We have observed that under conditions of code-switching, L1-L2 interaction does occur. Specifically, we have observed that the nondominant L1 exerted influence on the L2, whereas productions in the bilinguals' nondominant L1 (Greek) were free of L2-influence. Note that the acoustic measurement of VOT may be more sensitive to VOT effects than listener judgments that Flege et al. (2002) used. Indeed, Sancier and Fowler (1997) found that English listeners were insensitive to their bilingual's small but reliable acoustic measures of VOT shift in English when she returned to the US from months in Brazil.

The results of Experiment 1 demonstrate that early, Greek–English bilinguals who produce monolingual-like VOTs in Greek and English unilingual modes nonetheless show VOT shifts when code-switching, and these shifts are the result of unidirectional interference of the nondominant L1 on the dominant L2. However, recall that in our own previous work modest differences emerged between these bilinguals' VOTs in unilingual English mode and those of English monolinguals speakers in the phonetically more complex medial contexts (Antoniou et al., 2010). English and Greek differ in their medial VOT settings, in how they are affected by stress, and in the phonological status of the medial voiced stops. Therefore, we investigated medial stops in Experiment 2.

2. Experiment 2a: Medial post-vocalic stops

Unlike in initial-position, English voiced stops in word-medial intervocalic position are produced with voicing lead (e.g., Cox & Palethorpe, 2007). Voiceless stops are still produced with long-lag VOT, although stress position may affect the VOT of both English voiced and voiceless stops. For example, voiced stops have longer voicing lead and voiceless stops have longer lag in stressed syllables (Klatt, 1976).

In traditional accounts, Greek voiced stops in medial position are said to be produced with prenasalisation, for example [a^{m}ba], although voiced stops in certain words are never prenasalised (Newton, 1972). More recent evidence suggests that the prenasalisation is disappearing altogether from the speech of young Athenians (Arvaniti & Joseph, 2000), although no such observation has been made for the Greek spoken by Greek-Australians. In addition, the effects of stress on Greek VOTs are not agreed upon (Fourakis, 1986; Kollia, 1993), although we found previously that native monolingual Greek VOTs are generally less affected by stress than English VOTs (Antoniou et al., 2010). Thus to control for the variability in the production of Greek medial voiced stops, we specifically instructed participants to produce Greek medial voiced stops in an explicitly post-vocalic context (Experiment 2a), and in an explicitly post-nasal context (Experiment 2b).

If code-switching exacerbates the L1-interference observed in unilingual mode, then the effects of the L1 should be more pronounced in the medial contexts. Alternatively, the unclear status of Greek voiced stops might weaken the L1-interference observed in Experiment 1 in Experiments 2a and 2b.

2.1. Method

The participants were the same as those in Experiment 1.

The stimuli were recorded in the same recording session as for Experiment 1. The speakers also produced the stop consonants /p, t, b, d/ in word-medial post-vocalic context in stressed (VˈCV) /aˈpa, aˈta, aˈba, aˈda/ and unstressed syllables (ˈVCV) /ˈapa, ˈata, ˈaba, ˈada/. Stress was elicited using a stress diacritic in Greek and uppercase characters in English. Carrier phrases were the same as those in Experiment 1.

The procedure was identical to that in Experiment 1.

2.2. Results

A 2 × (2 × 2 × 2 × 2) ANOVA was conducted on the bilinguals' VOTs with the between-subjects factor of target language (Greek vs. English), and within-subjects factors of recording session (unilingual mode vs. code-switch), voicing (voiced vs. voiceless), place (bilabial vs. coronal) and stress (stressed vs. unstressed). Means and standard deviations of the VOTs for voiced and voiceless stops are presented in Table 3.

All significant effects and interactions are listed in Table 4. A significant main effect of target language confirmed the expected difference in mean VOT settings between Greek and English (M_{GREEK} = -43.8 ms; $M_{ENGLISH}$ = 14.3 ms). A significant main effect of recording session showed a shift towards negative VOTs in the code-switch recordings, suggesting that the overall effect of recording session was a shift towards the (longer lead/shorter lag) VOTs of Greek ($M_{UNILINGUAL-MODE}$ = -12.3 ms; $M_{CODE-SWITCH}$ = -17.2 ms).

Importantly, a significant Target Language × Recording Session interaction revealed that the difference in VOTs between the unilingual-mode recording and the code-switch recording was again greater for the English targets than the Greek targets ($Mdiff_{GREEK}$ = 7.1 ms; $Mdiff_{ENGLISH}$ = 16.9 ms). Unlike in Experiment 1, however, simple effects tests showed that both English, $F(1, 14) = 42.5$, $p < .001$, and Greek, $F(1, 14) = 7.5$, $p = .016$, were affected by the code-switch in opposite ways: Greek VOTs became more positive and English VOTs more negative. That is, the VOTs for each target language shifted toward the values of the other base language under the code-switch condition. Further, a significant three-way Target Language × Recording Session × Voicing interaction showed that that two-way interaction differed for voiced versus voiceless stops. From Figure 3, it appears that the effect of code-switching was more pronounced in voiced than voiceless stops. This was confirmed by simple two-way Target Language × Recording Session interactions (see Winer, 1971) that showed that code-switching affected voiced, $F(1, 14) = 28.8$, $p < .001$, but not voiceless stops. That is, Greek voiced stops were produced with shorter voicing lead (more English-like), and English voiced stops with longer lead (more Greek-like) in the code-switched utterances relative to those in unilingual mode.

In addition, a significant main effect of place revealed that the bilabials had longer voicing lead and shorter lag VOT than the coronal stops ($M_{BILABIALS}$ = -20.8 ms, $M_{CORONALS}$ = -8.6 ms). A significant Target Language × Stress interaction indicated that the overall difference in VOT between Greek and English stops was affected by stress. Simple effects tests (see Winer, 1971) confirmed that Greek and English stops differed in VOT in both stressed, $F(1, 14) = 40.0$, $p < .001$, and unstressed syllables, $F(1, 14) = 24.9$, $p < .001$. There was a larger difference in stressed syllables, where Greek stops overall had longer voicing lead and the English stops had longer lag (M_{GREEK} = -47.3 ms, $M_{ENGLISH}$ = 18.2 ms), than in unstressed syllables (M_{GREEK} = -40.2 ms, $M_{ENGLISH}$ = 10.4 ms). Effects and interactions not listed in Table 4 were nonsignificant.

2.3. Discussion

Similar to our observations for the initial-position stops in Experiment 1, in Experiment 2a the bilinguals produced clearly distinct VOTs for voiced and voiceless stops in both Greek and English. The Greek medial voiced stops had long voicing lead, the voiceless stops had short-lag VOT, and the English voiceless stops had long-lag VOT. The English voiced stops were prevoiced, compatible with what has been reported for English medial intervocalic stops (Cox & Palethorpe, 2007). Importantly, the voicing lead was shorter than that of the Greek voiced stops, which suggests that the bilinguals differentiate Greek [b] and [d] from English [p] and [t], even in the phonetically-complex medial positions (Antoniou et al., 2010). This observation extends to production the argument put forward by PAM-L2 for perception that language-specific phonetic categories exist for /b/ and /d/.

Also, similarly to Experiment 1, when code-switching, the bilinguals' productions were affected in the L2. This L1-interference was most prevalent in the increased lead VOT of the English medial voiced stops. However, unlike in Experiment 1, the bilinguals' productions of Greek targets were also affected by the code-switching, that is, there was also an L2 context effect on L1 productions. It is likely that the L2-influence on Greek (L1) voiced stops emerged because nonnasalised medial voiced stops are somewhat unnatural (infrequent) for Greek Australians, who tend to prenasalise their medial voiced stops. While the prenasalisation of medial voiced stops may be disappearing from the speech of young Athenian speakers (Arvaniti & Joseph, 2000), there have been no such reports for the Greek spoken in Australia. Moreover, it was the voiced stops, in both Greek and English, that were primarily influenced by code-switching. The voiceless stops remained largely unaffected. These findings demonstrate that in medial contexts, unlike initial contexts, code-switching results in bidirectional interference even in L2-dominant bilinguals.

We also observed place of articulation effects that have been reported to affect VOT as the place moves further back into the vocal tract (Klatt, 1975), and effects of stress that differed by language. Interestingly, it was the voiced stops, which were affected by stress in Greek productions, that showed VOT shifts following the code-switch. Perhaps the differing effect of stress for the voiceless stops (English = stress lengthens VOT lag, Greek = no effect of stress on VOT) prevented the L1 and L2 from influencing one another in voiceless stops, even in a code-switched utterance.

The results of Experiment 2a, while informative, still provide an incomplete picture of Greek stop-voicing in medial contexts. This is because Greek voiced stops may be prenasalised in medial position, most specifically in Australian Greek. Therefore, it is necessary to investigate the bilinguals' production of stops in medial post-nasal contexts as well, in order to fully understand the effects of L1-L2 interaction under the interlanguage condition of code-switching.

3. Experiment 2b: Medial post-nasal stops

3.1. Method

The participants were the same as those in Experiments 1 and 2a.

Speakers produced the stop consonants /p, t, b, d/ in word-medial post-nasal context in stressed (VNˈCV) /amˈpa, anˈta, amˈba, anˈda/ and unstressed syllables (ˈVNCV) /ˈampa, ˈanta, ˈamba, ˈanda/. Carrier phrases were the same as those in Experiments 1 and 2a.

The procedure was identical to that in Experiments 1 and 2a. These recordings were collected in the same session as in those experiments.

3.2. Results

As in Experiment 2a, a 2 × (2 × 2 × 2 × 2) ANOVA was conducted on bilinguals' VOTs with the between-subjects factor of target language (Greek vs. English), and within-subjects factors of recording session (unilingual mode vs. code-switch), voicing (voiced vs. voiceless), place (bilabial vs. coronal), and stress (stressed vs. unstressed). Mean VOTs and standard deviations for voiced and voiceless stops occurring in post-nasal contexts are presented in Table 5.

All significant main effects and interactions are listed in Table 6. A significant main effect of target language once again confirmed the expected differences in VOT between Greek and English (M_{GREEK} = -21.9 ms; $M_{ENGLISH}$ = 21.1 ms). As in Experiment 2a, the significant main effect of recording session showed that the overall mean VOTs had, on average, longer lead/shorter lag in the code-switch recordings than the unilingual-mode recordings ($M_{UNILINGUAL\text{-}MODE}$ = 4.0 ms; $M_{CODESWITCH}$ = -4.9 ms), suggesting an overall VOT shift towards the more negative VOTs of Greek.

Importantly, a significant Target Language × Recording Session interaction revealed that there was a difference in VOT between the unilingual-mode recordings and the code-switch recordings, more pronounced for the English targets than the Greek targets ($Mdiff_{GREEK}$ = -0.4 ms; $Mdiff_{ENGLISH}$ = 18.1 ms). Simple effects tests showed that the English VOTs were affected by the code-switch, $F(1, 14) = 31.4$, $p < .001$, but Greek VOTs were not. As in Experiment 2a, the three-way Target Language × Recording Session × Voicing interaction was also significant. As shown in Figure 4, the effect of code-switching appeared to be more pronounced in voiced stops. Simple two-way Target Language × Recording Session interactions (see Winer, 1971) revealed that code-switching affected VOT more for English than Greek voiced stops, $F(1, 14) = 13.4$, $p = .003$, and for English than Greek voiceless stops, $F(1, 14) = 8.2$, $p = .013$.

As in Experiment 2a, a significant main effect of place revealed that the bilabials had longer voicing lead and shorter lag VOT than the coronal stops ($M_{BILABIALS}$ = -5.0 ms, $M_{CORONALS}$ = 4.2 ms). A significant Target Language × Stress interaction indicated that the difference in VOT between Greek and English VNCV stops was affected by stress. Simple effects tests (see Winer, 1971) confirmed that Greek and English stops differed in VOT in both stressed, $F(1, 14) = 48.9$, $p < .001$, and unstressed syllables, $F(1, 14) = 42.4$, $p < .001$. As we had observed in the medial VCV stops in Experiment 2a, there was a larger difference in stressed syllables, where overall, Greek stops had longer voicing lead and the English stops had longer lag (M_{GREEK} = -25.5 ms, $M_{ENGLISH}$ = 23.1 ms), than in unstressed syllables (M_{GREEK} = -18.4 ms, $M_{ENGLISH}$ = 19.0 ms). Effects and interactions not listed in Table 6 were not significant.

3.3. Discussion

As expected, the bilinguals produced the language-specific VOT differences between Greek and English, even when stops were preceded by a nasal. Greek voiced stops were produced with voicing lead and the voiceless stops had short-lag VOT, whereas the English voiced stops were produced with voicing lead (shorter than that of the Greek voiced stops) and the English voiceless stops had long-lag VOT (Antoniou et al., 2010). Thus, even in the phonetically-complex, medial post-nasal positions — the context for which the phonological status of Greek voiced stops has been most questioned — the bilinguals' L1 still exerted unidirectional influence on the dominant L2.

Consistent with the results of Experiment 1 and partially consistent with Experiment 2a, code-switching affected the bilinguals' productions of the L2 (English) stops more than their productions of Greek stops. Specifically, the English post-nasal stops were affected by the code-switch; voiced stops were produced with more voicing lead, and voiceless stops with shorter lag (both more Greek-like).

As in Experiment 2a, we observed place effects. The bilabials had longer voicing lead and shorter lag VOT than the coronal stops. We also observed effects of stress that differed by language. Despite these language-specific stress differences, the L1 (Greek) exerted unidirectional influence on the dominant L2, and this was more pronounced in the longer lead VOTs of the English voiced stops in medial post-nasal position.

4. General Discussion

The present series of experiments was designed to examine the effects of language mode and code-switching on bilinguals' stop-voicing production in an attempt to clarify findings in the literature. We have shown that when bilinguals in Greek mode switched languages so as to produce English targets, their English VOTs were influenced by the surrounding Greek context, and drifted towards the shorter VOT values of Greek (voiced stops: longer lead,

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voiceless stops: shorter lag), relative to productions of the same targets in a unilingual Greek mode (Antoniou et al., 2010). This observation held true for stops occurring in initial, medial post-vocalic and medial post-nasal contexts. Only English medial post-vocalic voiceless stops were unaffected. These findings demonstrate that L1-interference on productions of stop voicing in the L2 occurs even in fluent early bilingual speakers who are L2-dominant. Thus, code-switching clearly appears to be a sensitive test of L1-L2 phonetic interaction at the phonetic level of gradient physical details, realised as VOT shifts of targets in one language towards those of the base language. This observation is compatible with studies that have demonstrated that there is a cost associated with code-switching at higher levels of language use (Altarriba et al., 1996; Grosjean, 1988; Kolers, 1966; Li, 1996; Macnamara & Kushnir, 1971).

We outlined four possibilities of interlingual interaction that could be observed in the VOTs of the code-switched targets. One hypothesis was that the L1 might exert unidirectional influence on the L2 (Caramazza et al., 1973), that is, the earlier-acquired L1 persistently interferes with production of the L2, even after many years of fluency, and even dominance, in the L2. On the other hand, if code-switching results in interlingual interference we might expect it to be bidirectional, meaning that the target language is affected by the base language, be it the L1 or L2, as posited by SLM hypothesis (Flege, 1995, 1999, 2002; Flege et al., 2003) and the gestural drift studies (Fowler et al., 2008; Sancier & Fowler, 1997). Alternatively, dominance in the L2 might lead to unidirectional influence on the L1, whereby due to their level of fluency in the L2, the bilinguals suppress L1-interference (Flege et al., 2002) and by extension the strength of the L2 influences production of the nondominant L1. A fourth possibility was that no L1-L2 interaction would occur, meaning that when bilinguals code-switch, they completely switch between languages and produce VOTs free of any interlingual interaction (Grosjean & Miller, 1994).

Our study provided a crucial test of these four possible outcomes of interlingual interaction. The findings suggest that the four possibilities of interlanguage interaction are not mutually exclusive. We observed different patterns of interlanguage interaction depending on the task that the bilinguals were asked perform (i.e., unilingual mode vs. code-switching).

Importantly, the L1-L2 interaction that we observed under code-switching was asymmetrical. Bilinguals were affected by the surrounding Greek (L1) context when code-switching to produce the English (L2) targets, but did not show comparable effects when they code-switched from English to produce the Greek targets. The only observation of L2-influence on the L1 was in Experiment 2a in which Greek voiced stops in medial VCV contexts were produced with shorter (more English-like) VOT lead. By contrast, in all experiments, a strong and robust effect of L1-influence on L2 targets was observed. This suggests that bilinguals are unable to suppress the L1 effect on L2 in production, despite their L2-dominance. This finding is consistent with persistent L1 effects on fluent bilinguals' speech production (e.g., Caramazza et al., 1973), and perception, even following years of L2 usage (Pallier et al., 2001; Sebastián-Gallés & Soto-Faraco, 1999; Sebastián-Gallés et al., 2005). Yet our study stands apart from the perceptual findings of the Sebastián-Gallés and colleagues in two important respects: Firstly, we investigated the bilinguals' speech production rather than perception (in both unilingual mode and when code-switching), and secondly, our bilinguals were dominant in the L2, unlike their Spanish–Catalan bilinguals. We observed L1-interference on the L2 in code-switches, even for highly-fluent L2-dominant bilinguals. The interference of the L1 on the L2 seems to be more persistent in production than has been reported or even speculated about previously.

The present findings are at least partially inconsistent with the "bidirectional interaction" accounts of Flege and Eefting (1987b), Fowler et al. (2008) and Sancier and Fowler (1997), who reported gestural drift in both languages of bilinguals, towards those of the language environment. It seems that our Greek–English early bilinguals keep their languages separate, at least more successfully than the late bilingual of the gestural drift study. However, the changes we observed were brought about following a short period of effectively unilingual conversation (excluding the code-switched target) leading up to, and during, the recording procedure. We cannot rule out that prolonged exposure, such as an overseas stay, would not result in changes in both languages even for our bilingual sample. Yet our findings have strong implications for the concept of gestural drift and its relevance to understanding bilingual management of the phonetic settings of their two languages under different language contexts. Future work should attend more to differences in order of acquisition and language dominance relative to native monolinguals of each language. For instance, if L2-dominant bilinguals show L1 effects on their L2, we would expect L1-dominant bilinguals to show even stronger L1-interference when code-switching. We also recommend examining voiced stops in gestural drift studies, in addition to voiceless stops, as L1-interference was more prevalent in the longer lead VOTs of the English (L2) voiced stops than in voiceless stops.

Our findings do not support Flege et al.'s (2002) assertion that L2-dominant bilinguals are the most likely to suppress L1-L2 interference. Our findings demonstrated just the opposite: that even after years of L2 dominance the bilinguals were still systematically influenced by their nondominant L1. This observation was robust across all contexts.

The L1-L2 interference observed here also is inconsistent with the findings of Grosjean and Miller (1994) who reported cases of French–English bilinguals who code-switched completely with no French influence on their English. Our findings demonstrate that for carefully selected, early bilinguals who are L2-dominant, phonetic "bleeding," or lack of complete switch from one language to the other, may occur between the L1 and L2 in code-switched utterances. These effects are observable not just at the code-switch boundary (in word-initial position), but also when the stops occur in medial positions. Importantly, the effects between the L1 and L2 were asymmetrical, and in the same direction in all contexts.

SLM (Flege, 1995, 1999, 2002; Flege et al., 2003) would need to be revised to account for the performance of our bilingual speakers. This is because (a) in a unilingual mode the bilinguals' productions of stop VOTs in both the L1 and L2 were indistinguishable from those of monolinguals, and (b) when code-switching, the phonetic interference that was observed was largely of the L1 on the dominant L2. Therefore, activating a bilingual's two languages may result in "bleeding" from the phonetic settings of the L1 into the L2. According to SLM, compromise VOT values might be produced if the stops are identified as "similar" across the bilinguals' two languages. But, SLM cannot account for why this would be exacerbated in code-switching, nor why in unilingual mode, the Greek–English bilinguals produced monolingual-like VOTs in both languages (Antoniou et al., 2010). The cross-language phonetic interference observed in the code-switches was a result of our deliberate attempt to induce L1-L2 interaction. Despite our best efforts, the L1 remained largely unaffected by code-switching from an L2 context in initial position, and a modest L2-influence on L1 (Greek) was only observed in the "unnatural" nonnasal medials for these Australian Greek speakers, who tend to prenasalise voiced stops in medial positions.

As we have argued, the principles of PAM-L2 (Best & Tyler, 2007) can be extended to speech production. For instance, the formation of language-specific phonetic categories could conceivably account for monolingual-like performance in speech production (Antoniou et al., 2010). However, even if PAM-L2 was extended to production, it is not equipped to explain the differing observed effects of interlanguage interaction in unilingual mode (minimal interlanguage interaction) and when code-switching (L1-influence on the L2).

The observed shift in interlanguage interference is consistent with the Language Mode framework (Grosjean, 1982, 1989, 1998, 2001, 2008). In unilingual mode, the bilinguals' productions were monolingual-like, suggesting no L1-L2 interaction, with the caveat that modest differences from monolinguals emerged in some of the English (L2), but not Greek (L1), stops in the phonetically complex medial contexts (see Antoniou et al., 2010). Under the interlanguage condition of code-switching, this modest L1-influence was exacerbated and we observed robust L1 effects on code-switched L2 targets. This difference between the two conditions highlights the importance of the situational language context for bilinguals' production of speech. Bilinguals may undergo a short-term productive reattunement, depending on the linguistic setting. Neither SLM, nor an extended version of PAM-L2, account for why we have observed two of the four possibilities of interlingual interaction within the same speakers: minimal L1-L2 interaction in unilingual mode, and L1-influence on the L2 when code-switching. Our results show that theories attempting to account for interlanguage effects on bilingual speech production must take heed of situational effects, as argued by the Language Mode framework.

Why do the bilinguals, who produce monolingual-like VOTs in unilingual mode, show VOT shifts when code-switching? We propose that placing a bilingual in a unilingual mode suppresses the influence of the temporarily dormant language. On the other hand, the code-switch activates both languages and the effects of L1-L2 phonetic bleeding may be observed. The fact that a shift occurs at all suggests that, at some abstract level, the phonetic categories of each language must be perceived as similar or linked (e.g., Greek [p] and English [p^h] are language-specific phonetic variants of the interlanguage /p/ category). Further, the asymmetrical influence of the L1 on the L2 perhaps suggests that even during fairly early L2 acquisition, those new categories that are established are linked to those of the L1, and the categories of the L1 maintain an effect on those of the L2, even after years of L2-dominance.

The unidirectional L1-influence on the L2, most pronounced in the initial-position stops, may reflect the bilinguals' language-usage patterns even in code-switching contexts. In every day usage, Greek–English bilinguals are far more likely to insert Greek words into English frames than the other way around, as English serves as the base language for the majority of their communication. Perhaps the limited English influence on the production of code-switched Greek targets is the result of years of code-switching practice where English has served as the base language.

In conclusion, cross-language phonetic influence occurs in the speech of highly fluent, early, L2-dominant bilinguals when they switch languages, with the caveat that this influence is more evident in one language than the other. Our results suggest that the L1 is less susceptible to phonetic interference than the L2, even for bilingual speakers who are L2-dominant, and that this effect is exacerbated when code-switching.

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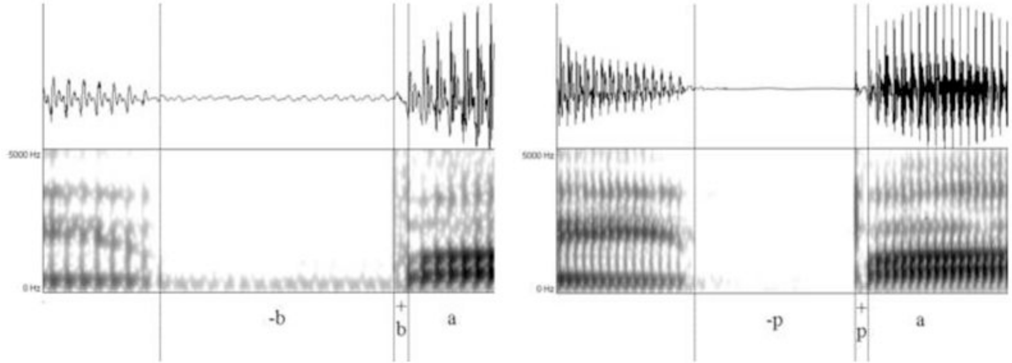

Figure 1.

Oscillograms and spectrograms illustrating VOT measurement protocol. On left, negative VOT is reported, denoted by -b. On right, positive VOT reported, denoted by +p.

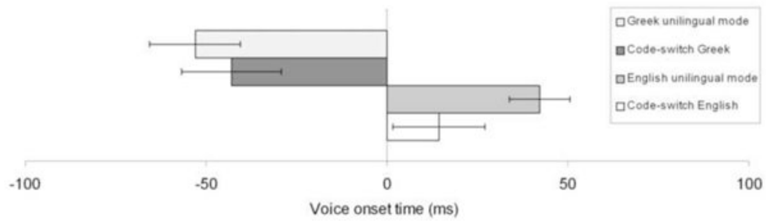

Figure 2.
Bilinguals' mean VOTs in Greek and English initial-position stops across voiced and voiceless targets produced in unilingual modes and from code-switches. Error bars indicate standard error of the mean.

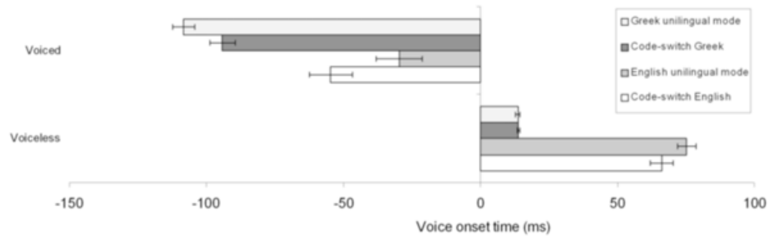

Figure 3.
Bilinguals' VOTs of Greek and English voiced and voiceless stops in medial post-vocalic positions produced in unilingual modes and from code-switches. Error bars indicate standard error of the mean.

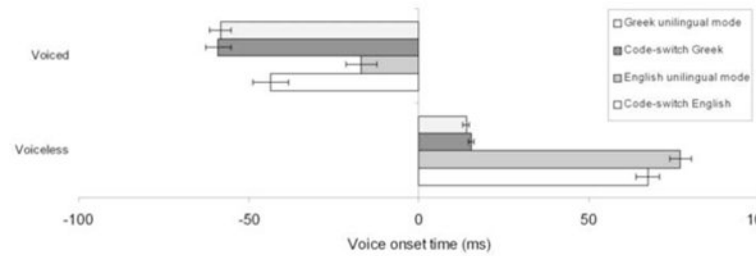

Figure 4.
Bilinguals' VOTs of Greek and English voiced and voiceless stops in medial post-nasal positions produced in unilingual modes and from code-switches. Error bars indicate standard error of the mean.

Table 1

Mean VOTs (M: boldfaced) and standard deviations (SD) of bilingual speakers' productions of Greek and English stops in initial position in unilingual mode and when code-switching from the base language.

Language Mode	ba		da		pa		ta	
	M	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Greek targets group								
Unilingual	**-117.9**	27.1	**-122.1**	30.3	**12.4**	2.4	**15.3**	6.5
Code-switch	**-111.4**	52.7	**-108.7**	46.0	**23.7**	33.6	**25.0**	16.1
English targets group								
Unilingual	**-8.4**	23.6	**9.0**	21.1	**76.1**	19.3	**91.9**	19.9
Code-switch	**-37.8**	52.6	**-55.0**	45.5	**68.6**	24.4	**81.8**	15.9

Table 2

Significant main effects and interactions for Experiment 1, for Greek and English /p, t, b, d/ in initial position.

Effect	$F(1, 14)$	p	η_p^2
Target language	77.6	<.001	.847
Voicing	548.2	<.001	.975
Target language × Voicing	9.7	.008	.408
Target language × Recording session	10.8	.005	.436

Table 3

Means (in bold) and standard deviations of VOTs in bilingual speakers' productions of Greek and English voiced and voiceless stops in medial stressed and unstressed positions in unilingual mode and in the context of code-switching from the base language.

Language mode	aˈba		aˈda		ˈaba		ˈada		aˈpa		aˈta		ˈapa		ˈata	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Greek targets group																
Unilingual	**-129.7**	19.5	**-108.3**	19.2	**-104.8**	21.7	**-90.8**	12.7	**13.1**	2.6	**13.4**	4.9	**13.1**	4.7	**15.5**	5.9
Code-switch	**-103.0**	42.4	**-90.4**	20.9	**-101.3**	16.4	**-82.3**	18.5	**12.5**	1.7	**13.8**	2.2	**12.9**	2.7	**16.2**	4.0
English targets group																
Unilingual	**-34.0**	53.4	**-11.8**	41.1	**-46.1**	54.7	**-27.1**	41.5	**74.5**	12.3	**85.5**	17.5	**66.7**	19.6	**74.5**	22.3
Code-switch	**-67.1**	46.3	**-46.3**	53.0	**-60.7**	47.0	**-44.4**	35.0	**66.9**	27.9	**77.8**	13.9	**54.2**	27.7	**66.5**	20.3

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Table 4

Significant main effects and interactions for Experiment 2a (Greek and English /p, t, b, d/ in medial post-vocalic position).

Effect	$F(1, 14)$	p	η_p^2
Target language	34.0	<.001	.708
Recording session	7.2	.018	.338
Voicing	317.8	<.001	.958
Place	16.8	.001	.546
Voicing × Place	10.4	.006	.425
Target language × Stress	9.3	.009	.546
Target language × Recording session	42.8	<.001	.754
Target language × Recording session × Voicing	8.2	.012	.370

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Table 5

Mean VOTs (in bold) and standard deviations of bilingual speakers' productions of Greek and English voiced stops in medial postnasal position in unilingual mode and in code-switching from the base language.

Language mode	amˈba		anˈda		ˈamba		ˈanda		amˈpa		anˈta		ˈampa		ˈanta	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Greek targets group																
Unilingual	**-69.3**	18.7	**-62.1**	21.7	**-57.5**	8.0	**-43.9**	13.8	**12.7**	2.9	**14.5**	6.2	**14.0**	5.2	**14.8**	5.7
Code-switch	**-68.2**	27.7	**-61.1**	24.6	**-56.4**	13.8	**-49.8**	14.9	**12.6**	3.0	**17.1**	6.2	**14.6**	3.2	**17.2**	4.5
English targets group																
Unilingual	**-21.2**	31.1	**0.5**	22.8	**-27.2**	22.5	**-19.5**	22.7	**77.2**	17.0	**84.6**	18.0	**70.4**	16.2	**76.0**	21.3
Code-switch	**-55.5**	36.2	**-44.8**	26.8	**-45.1**	26.4	**-28.2**	27.7	**64.6**	20.4	**79.5**	11.0	**54.3**	21.3	**71.6**	16.0

Table 6

Significant main effects and interactions for Experiment 2b (Greek and English /p, t, b, d/ in medial post-nasal position).

Effect	***F*(1, 14)**	***p***	η_p^2
Target language	50.4	<.001	.783
Recording session	15.1	.002	.519
Voicing	674.8	<.001	.980
Place	20.0	.001	.588
Target language × Voicing	18.6	.001	.570
Target language × Stress	7.9	.014	.360
Recording session × Voicing	7.8	.014	.358
Recording session × Stress	6.7	.022	.323
Voicing × Stress	4.9	.045	.258
Target language × Recording session	16.3	.001	.538
Target language × Recording session × Stress	11.0	.005	.439
Recording session × Voicing × Stress	5.2	.039	.270
Target language × Recording session × Voicing	4.8	.046	.255
Target language × Recording session × Voicing × Stress	8.9	.010	.389