Voice onset time in bilingual German-Spanish children

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This study examines the acquisition of the voicing contrast in German-Spanish bilingual children, on the basis of the acoustic measurement of Voice Onset Time (VOT). VOT in four bilingual children (aged 2;0–3;0) was measured and compared to VOT in three monolingual German children (aged 1;9–2;6), and to previous literature findings in Spanish. All measurements were based on word-initial stops extracted from naturalistic speech recordings. Results revealed that the bilingual children displayed three different patterns of VOT development: 1. Delay in the phonetic realization of voicing: two bilingual children did not acquire long lag stops in German during the testing period; 2. Transfer of voicing features: one child produced German voiced stops with lead voicing and Spanish voiceless stops with long lag voicing; and 3. No cross-language influence in the phonetic realization of voicing. The relevance of the findings for cross-linguistic interaction in bilingual phonetic/phonological development is discussed.

Introduction

The acquisition of the voicing contrast in bilingual and second language acquisition has been a major topic in the phonetic literature during the last two decades. Results of numerous studies indicate that this particular phonetic capability may be influenced by the simultaneous or sequential acquisition of two languages. Findings are most striking for the acquisition of a second language (L2), where it has been shown that L2 learners may never acquire target-like Voice Onset Time (VOT) values in their second language. In particular, L2 learners who begin learning a second language as adults often produce 'compromise' VOT values, which are intermediate to the VOT values of the two languages (Williams, 1980; Flege and Port, 1981; Flege, 1991; Laeufer, 1996). Individuals who learn a second language in early childhood, however, may produce VOT values that do not differ from the values produced by monolingual individuals (Flege, 1991). In bilingual first language acquisition (the simultaneous acquisition of two languages from birth), there is currently insufficient information to address the question when bilingual children begin to operate with VOT values that are comparable to those of their monolingual counterparts. The aim of this study is to provide further information on the development of the voicing contrast in a young population of bilingual children – bilingual German-Spanish children aged two to three years. In so doing, we seek to address fundamental questions in bilingual acquisition, such as 'Do the phonetic/phonological systems of bilingual children develop independently or do they influence each other?' We commence by describing the voicing contrast in German and Spanish and by summarizing the respective monolingual and bilingual literatures on VOT acquisition.

The voicing contrast in German and Spanish

Both German and Spanish have voiced (b,d,g) and voiceless stop consonants (p,t,k), but the phonetic basis underlying the voicing distinction is different in the two languages. The best way to capture this phonetic difference is through the acoustic measurement of VOT. This measure may be defined as the time interval (ms) between the onset of vocal fold vibration and the release of the articulators. The timing relationship between these two events is expressed on a continuum, such that voicing which occurs before the release of the articulators is given a negative VOT value, and voicing which occurs after the release, a positive VOT value. The seminal work of Lisker and Abramson (1964) established three cross-linguistic categories of voicing based on VOT: voicing lead, short lag, and long lag.

In German, the opposition is one between long lag and short lag. Voicing begins long after the release of the articulators for voiceless stops, and coincides with or occurs shortly after the release of the articulators for voiced stops. Braunschweiler (1997) reports VOT means of 51 ms and 16 ms for voiceless and voiced German

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German Stops

/b,d,g/ /p,t,k/

----------------------- 0 ------------ ------------

(short lag) (long lag)

Spanish Stops

/b,d,g/ /p,t,k/

----------------------- 0 ------------ ------------

(lead) (short lag)

Voice Onset Time

Figure 1. Schematic representation of VOT indicating differences between German and Spanish VOT values (adapted from Deuchar and Clark, 1996).

stops, respectively. Taylor (1975) reports similar results: Approximately 50 ms for voiceless stops and less than 20 ms for voiced stops. In Spanish, the opposition is one between short lag and lead. Voicing coincides with or occurs shortly after the release of the articulators for voiceless stops, and begins well before the release of the articulators for voiced stops. Lisker and Abramson (1964) report ranges of 0–55 ms for voiceless stops and between −45 and −235 ms for voiced stops in Spanish. Castañeda (1986) cites VOT means of 14 ms and −69 ms for voiceless and voiced Spanish stops, respectively. Voiced stops in German are produced similarly to voiceless stops in Spanish, whereas voiced stops in Spanish are phonetically truly voiced. The difference between German and Spanish VOT values is shown in Figure 1 (adapted from Deuchar and Clark, 1996, p. 352).

VOT also varies with place of articulation. The main finding is: the further back the closure, the longer the VOT (Lisker and Abramson, 1964; Volatis and Miller, 1992). This leads to velar stops having the longest VOT values, bilabial stops, the shortest, and alveolar stops having intermediate values.

Monolingual acquisition of VOT

Short lag versus long lag

The acquisition of VOT has been most frequently studied in English, which, like German, has a contrast between short versus long lag stops. Studies with young English-speaking children indicate that there are several stages in the acquisition of VOT (Zlatin and Koenigsknecht, 1976; Macken and Barton, 1979). These stages are shown schematically in Figure 2. Initially, children produce target voiced and voiceless stops in the short lag region and the difference between the mean VOT values for each pair is not significantly different. They then pass through a stage in which they again produce both pairs of stops in the short lag region, but they produce target voiceless stops with significantly longer VOTs than target voiced stops. However, an adult listener may not perceive the voicing difference between these two types of stops. Finally, they produce short lag values for target voiced stops and long lag values for target voiceless stops often with a tendency, in the case of the latter, to overshoot the mark and produce values more extreme than the adult

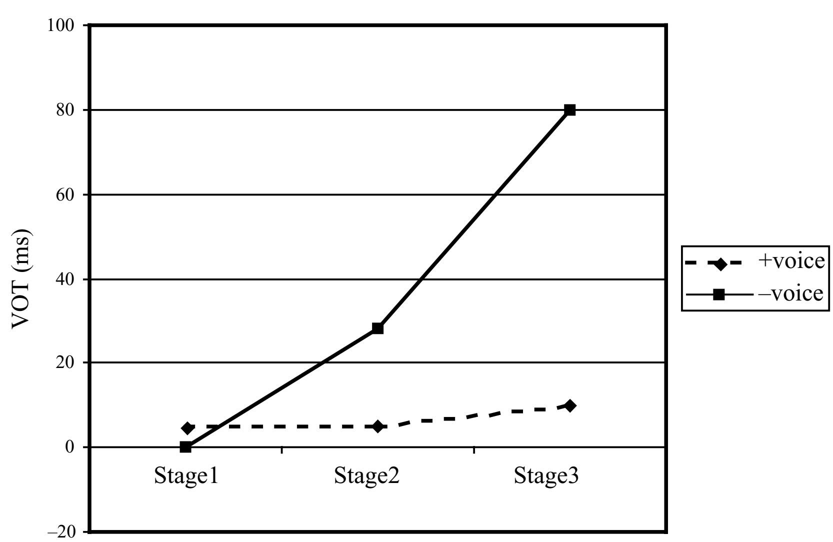

Figure 2. Stages of VOT acquisition in a target language containing the long versus short lag contrast (stages are based on findings reported by Macken and Barton, 1979).

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means.[1] This final stage is reported to occur at around the age of two years (Zlatin and Koenigsknecht, 1976; Macken and Barton, 1979; Davis, 1995; Snow, 1997). Gradual refinement and stabilization of VOT occurs later, however, and even six-year-olds may differ from adults in the finer temporal aspects of VOT acquisition.

Lead versus short lag

VOT findings are less straightforward for those languages in which the contrast is one between lead and short lag. Studies with French, Spanish, Hindi, Thai, and Arabic children (all languages that contain lead stops) conclude that lead voicing is acquired late and may not be acquired with adult-like values even by the age of five years (Macken and Barton, 1980; Allen, 1985; Gandour, Petty, Dardarananda, Dechongkit and Munkgoen, 1986; Davis, 1995; Khattab, 2000). For example, Macken and Barton (1980) reported that not even by 3;10 could Spanish-speaking children produce voiced and voiceless cognates differently on the basis of adult-like voicing values; Davis (1995) found that by two years, Hindi children produced only 45% of target voiced stops with lead voicing; and Khattab (2000) observed that two Lebanese Arabic-speaking children (age 5;0 and 7;0) did not consistently produce lead voicing.

Why is lead voicing acquired late? Macken and Barton (1980) proposed two possible explanations for Spanish. The first is that lead voicing is inherently more difficult to produce and learn than lag voicing. The second is that the Spanish spirantization rule interferes with the acquisition of contrastive voicing. In Spanish, voiced stops undergo spirantization in non-utterance-initial position (voiced stops [b,d,g] occur in utterance-initial position and after nasals, and [d] after /l/; spirants occur elsewhere). Macken and Barton (1980) observed that adults (Mexican dialect) frequently produced target stops as spirants not only in utterance-medial position but also in utterance-initial position, leading them to conclude that VOT was not the most critical phonetic feature underlying the Spanish voicing contrast; rather, spirants played a greater role. The fact that the Mexican children tested by Macken and Barton (1980) often produced utterance-initial voiced stops as spirants was interpreted as reflecting patterns of the adult target language.

Macken and Barton's (1980) conclusion, although relevant to Spanish, cannot be considered as a universal explanation for all the data because lead voicing is acquired late in other languages, which do not contain allophonic variation between stops and spirants. Macken and Barton's first argument – that lead stops are articulatorily more complex than lag stops – has been entertained by several other researchers (Kewley-Port and Preston, 1974). To produce lead voicing, the child needs to use different muscle gestures from those used in short lag stops. Nevertheless, as Davis (1995) points out, 'articulatory complexity' is not an easy term to quantify and the fact that babbling infants frequently produce lead stops suggests that other factors are at play. Davis (1995), instead, appeals to the acoustic difference between the lag-times of the members of a voicing contrast in explaining the late acquisition of lead voicing. To understand Davis' proposal, it is important to realize that pre-voiced stops can be characterized by two measures: the traditional lead-time as well as the lag-time measure. Pre-voicing is usually followed by a short voiceless interval or lag after stop release. The lag-time of pre-voiced stops refers to this short interval between stop release and the recurrence of voicing (Davis, 1995, footnote 3). That lag-time takes perceptual precedence over lead-time is suggested by acoustic studies showing that lead VOT differences are less well discriminated than lag differences (Aslin and Pisoni, 1980). According to Davis' findings, based on the acquisition of VOT in Hindi, the contrast between lead and short lag stops is acquired late because the magnitude of the lag difference between the two types of stops is very small.[2]

Interestingly, several studies have reported that children may make a distinction between target voiced and voiceless stops through other means apart from the use of lead voicing. These include: production of continuous voicing (Macken and Barton, 1980; Allen, 1985); spirantization of voiced stops (Macken and Barton, 1980), and use of a significant VOT distinction in the short lag region (Macken and Barton, 1980).

Based on the preceding summary of the monolingual literature, we expect bilingual children to develop an adult-like voicing contrast in German by the age of two years, but one in Spanish substantially later. Given the apparent difficulty of the lead–short lag distinction in Spanish, we will examine whether exposure to two languages offers different kinds of solutions to the bilingual child.

Bilingual acquisition of VOT

Numerous studies have measured VOT in bilingual individuals (Bond, Eddey and Bermejo, 1980; Williams, 1980;

[1] The extreme long lag values reported in child speech are most likely due to instability and lack of control in the early use of aspiration (Macken and Barton, 1979).

[2] The current study focuses on the phonetic features underlying the voicing contrast. It could also be possible to concentrate on the phonological features. English voiced and voiceless stops are differentiated by the features [–spread glottis] and [+spread glottis] whereas Spanish voiced and voiceless stops are differentiated by the features [–voice] and [+voice]. Davis (1995) concluded that acoustic factors (e.g. VOT) appear to be more important than phonological factors in the acquisition of the voicing contrast (see also Deuchar and Clark, 1996).

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Konefal and Fokes, 1981; Flege, 1991; Watson, 1991; Deuchar and Clark, 1996; Laeufer, 1996; Heselwood and McChrystal, 1999, 2000; Khattab, 2000; Yavas, 2002; Johnson and Wilson, 2002); however, relatively few have focused on children around the ages of two to three years. One exception is Deuchar and Clark's (1996) case study of a Spanish-English bilingual child, Manuela, aged 1;7–2;3. Deuchar and Clark observed that Manuela developed a voicing contrast at 2;3 in English, but not in Spanish. The child produced voiced stops as short lag and voiceless stops as long lag in English, but produced voiced and voiceless stops predominantly as short lag in Spanish without the use of lead voicing. However, she produced target voiceless stops with longer VOTs than target voiced stops in Spanish, suggesting a primitive VOT distinction.

Looking more closely at Deuchar and Clark's (1996) study, it is difficult to determine whether bilingualism plays a role in explaining their findings, because their results are consistent with those of the respective monolingual populations. Manuela made a voicing contrast in English shortly after the age of 2;0 as do monolingual English children, and not one in Spanish, as is frequently the case with monolingual Spanish children of the same age. In a similar vein, Khattab (2000) stresses the importance of distinguishing between the influence of bilingualism and developmental factors. Her comparison of the VOT development of three English-Arabic bilingual children (ages 5, 7, and 10 years) and their respective monolingual controls revealed little that could be directly related to their bilingualism. All three bilingual children produced VOT values for long lag and short lag stops in English that were similar to those measured for the monolingual English children. Two of the bilingual children did not produce lead stops in Arabic but neither did all the monolingual Arabic children. One point of difference was that acquisition of lead voicing correlated with age in the monolingual Arabic population, but not in the bilingual population. The seven-year-old bilingual child produced Arabic voiced stops with lead voicing, but the youngest and oldest children did not. Khattab (2000) points out, however, that the ten-year-old child's failure to produce voicing lead may not be due to interference from English but due to insufficient Arabic input in his early childhood.

The above findings have implications for the question of whether the two voicing systems are differentiated or non-differentiated from the beginning. It has been claimed that the bilingual child initially has access to a unitary system that differentiates into two systems only later in development (Volterra and Taeschner, 1978). Deuchar and Clark's (1996) results do not support this claim. They documented target-like English VOT values in their subject by 2;3 (some differentiation even by 1;11), suggesting two separate voicing systems early on in development. Nevertheless, even if the systems are separated, they may not be completely independent but may interact. This interaction may manifest as delay or acceleration in the acquisition of voicing features, or as transfer (Paradis and Genesee, 1996). Delay may manifest itself in German if the short–long lag distinction is still not acquired at about 2 years of age. Acceleration may manifest itself in Spanish if the short lag–lead distinction is acquired earlier than it is normally observed in monolingual children. Transfer may result if bilingual children employ voicing features from one of their languages in the other target language. For example, they may make a contrast based on short versus long lag in Spanish. In that case, transfer could be interpreted as a strategy to accelerate the acquisition of the voicing contrast in Spanish. This type of acceleration has been dubbed bilingual bootstrapping by Gawlitzek-Maiwald and Tracy (1996). We discuss some of these patterns below.

Several studies have shown that bilingualism may lead to delay in the acquisition of voicing features (Bond et al., 1980; Konefal and Fokes, 1981; Yavas, 2002). The findings of this group of studies are not directly comparable to the previous ones, however, because they are based on subjects who are consecutive bilinguals, that is, monolingual in one of the languages for several years in early childhood. For example, Bond et al. (1980) reported on a Spanish-English bilingual child, age 4 years, who was later tested by Konefal and Fokes (1981) at 7 years. At 4 years, the child had only been exposed to English for six months. At this age, she maintained a significant voicing distinction for VOT in the short lag region in both Spanish and English but her English VOT values were not yet target-like. At 7 years, she produced short and long lag stops consistently in English, and short lag and lead stops in Spanish indicating target-like acquisition of VOT in both languages. Yavas (2002), concentrating only on voiceless stops, reported instability in the acquisition of VOT by 10 Spanish-English bilingual children (aged approximately 7 years) with two children failing to differentiate the two languages. However, all of his subjects had only received consistent exposure to English since entering school at the age of 5–6 years.

Other studies on bilingual VOT report findings consistent with the transfer of voicing features. Williams (1980) noted that the VOT values of English-Spanish bilingual adults corresponded to monolingual values with one exception: the productions of English voiced stops contained a higher amount of lead voicing, a finding that was attributed to the influence of Spanish. Similarly, Heselwood and McChrystal (2000) found that Panjabi-English bilingual children (aged approximately 10 years) produced a higher proportion of English voiced stops with lead voicing than monolingual English children.[3]

[3] Panjabi has a voicing opposition between lead and short lag stops, as do Japanese and French (see next paragraph).

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Johnson and Wilson's (2002) study of the acquisition of VOT by two English-Japanese bilingual children (mean age 2;11 and 4;9) is consistent with the transfer of long lag voicing features. The VOT values for both children fell into the long lag region for target English and Japanese voiceless stops, even though target voiceless stops in Japanese are typically produced as short lag. Nevertheless, the older child produced English stops with longer VOTs than Japanese ones, suggesting that she was still trying to make some form of distinction between the two languages. Similarly, Watson (1991) reports that French-English bilingual children (aged 6 and 10 years) produced French voiceless stops with significantly more aspiration than monolingual controls.

Summary and purpose of study

Summing up the literature: Studies on monolingual VOT acquisition indicate that around the age of two years, children acquire a target-like contrast between short and long lag stops, but later than two years, perhaps even later than four to five years, children acquire a target-like contrast between lead and short lag stops. Studies on bilingual VOT development report varied findings: some studies reveal few effects unambiguously due to bilingualism (Deuchar and Clark, 1996; Khattab, 2000) whereas others indicate delay, in the case of consecutive bilingualism (Bond et al., 1980; Yavas, 2002), or transfer of voicing features (Williams, 1980; Heselwood and McChrystal, 2000; Johnson and Wilson, 2002). These findings are consistent with differentiation (Deuchar and Clark, 1996) but also with interaction between the two voicing systems (Williams, 1980; Johnson and Wilson, 2002).

Given that there are few existing studies on the acquisition of VOT in very young bilingual children (aged two to three years), the aim of this study is to address this deficit. This study will expand upon Deuchar and Clark's (1996) study, which is based on one child, and Khattab's (2000) study, which is based on older children. Specifically, the study will investigate the acquisition of VOT in four bilingual children (age 2;0–3;0 years) acquiring German and Spanish simultaneously from birth. VOTs in the bilingual children will be compared to those of a monolingual control group (German) and to existing literature findings (Spanish).

Method

Subjects and data collection

Subjects include three monolingual German children (Bernd, Britta, and Thomas) and four bilingual German-Spanish children (Robert, Stefan, Nils, and Simon) growing up in Germany.[4] All bilingual children are children of Spanish-speaking mothers (in two cases, Mexican; in one case, Chilean; and in one case, Spanish)[5] and German-speaking fathers. The main care person during the first two years of life for the bilingual children was the Spanish-speaking mother. The parents followed the *une personne, une langue* rule by addressing the child in his/her respective language. The parents' language of communication was generally German except in the case of Simon, whose parents report communicating in Spanish with each other. Most children began attending a German day care center at 3;0, after the time period considered in this article, except for Nils, who attended one already at age 1;5.

Children were audio- and video-recorded fortnightly from the beginning of word production (1;0 to 1;3) through to approximately 2;6–3;0 years. They were recorded in their homes in unstructured play situations, while interacting with one of the parents and an investigator. The bilingual children were visited by two separate teams: a German- and a Spanish-speaking team. If one of the parents was present, he/she had to be a native speaker of the language in which the recording was taking place. Only German words spoken in German sessions and Spanish words spoken in Spanish sessions were included in the study. Following testing, all sessions were glossed and phonetically transcribed.

Data analysis

From the entire testing period, time periods (organized in three-month intervals) were individually selected for each child based on their VOT capabilities.[6] For example, Britta had already acquired target-like VOT values by 1;9–2;0; therefore, no further time period was analyzed for this child. Target words containing stop consonants in word-initial stressed position were selected from the data sessions during these time periods for VOT analysis. Examples of commonly occurring target words

[4] The three monolingual children were tested as part of the project PAIDUS (Parameter Fixing in German and Spanish) supported by a grant of the Deutsche Forschungsgemeinschaft (DFG) to Conxita Lleó; two of the bilingual children were tested as part of the DFG project PEDSES (Phonological Acquisition of German and Spanish as First Languages); and the other two bilingual children were tested as part of the bilingual project 'Prosodic constraints on the phonological and morphological development of bilingual acquisition', carried out at the Research Centre on Multilingualism, University of Hamburg, under the direction of Conxita Lleó, also supported by the DFG, to which we express our gratitude.

[5] We are unaware of any systematic VOT differences among Spanish dialects.

[6] Time intervals refer to the interval up to but not including the final date. Therefore, the interval 1;9–2;0 refers in reality to 1;9,0–1;11,30. Note that we present Robert's results for a four-month rather than a three-month time interval (i.e. 2;0–2;4) because testing sessions were discontinued as of age 2;4.

Table 1. *Examples of target words measured in the VOT analysis.*

Stops	German	Spanish
p	Post, Puppe, putzen	pan, pato, pista
b	Bild, Boot, Bagger, besser	barco, bella, vacas
t	Tisch, Tuch, Teller, Teddy	tapa, torta, tigre
d	Deckel, dunkel, duschen, diese	dos, dulce, donde
k	Keks, Katze, Kissen, Kurve	coche, cuna, casa, cama
g	gut, gelb, ganz, Gurke, Gabel	gato, gallo, ganso

Table 2. *Percentages of utterances representing the target language in German and Spanish sessions.*

Child	Period	German sessions	Spanish sessions
Robert	2;0–2;4	75% (983/1311)	43% (302/709)
Stefan 1	2;3–2;6	74% (474/641)	85% (340/398)
2	2;9–3;0	86% (1024/1195)	86% (687/795)
Simon 1	2;0–2;3	90% (289/322)	99% (562/569)
2	2;3–2;6	96% (841/877)	99% (928/935)
Nils 1	2;0–2;3	86% (667/774)	85% (650/767)
2	2;3–2;6	98% (478/488)	60% (336/564)

are provided in Table 1. Target words were generally content words but occasionally, due to limited numbers of tokens, stressed function words (e.g. German *da* 'there', *der* 'the/he') were included. An attempt was made to select approximately 10 tokens per Place of Articulation per time period. However, because the data are naturalistic, it was not always possible to obtain the required number of words per condition. In particular, target words containing word-initial voiced stops were difficult to find in Spanish, because they are not as numerous as those beginning with voiceless stops, and because they are often embedded within longer utterances, which may lead to spirantization of the voiced stop.[7] When a time period contained a large number of potential target forms, words were randomly selected from the data pool such that a maximum of 15 words was included. We also attempted to balance tokens across number of syllables in a word (one versus two + syllables) because timing factors may influence VOT measures (see e.g. Volatis and Miller, 1992). This factor is important when comparing German and Spanish, because a Spanish child's corpus contains a higher percentage of multisyllabic words than a German child's (Lleó, 1998; Lleó and Demuth, 1999).

VOT was measured using the program Soundscope for the Macintosh. VOT, measured in ms, was taken to be the interval between the release burst and the first clear glottal pulse as shown on the waveform (positive peak) and corresponding spectrogram (usually the beginning of the second formant; Davis, 1995). In the case of pre-voiced tokens, two values were measured: 1. Lead VOT (duration of voicing prior to release) and 2. Lag VOT (period between release burst and first glottal pulse after the release). VOT measurement is illustrated in Figure 3, using examples from the children's utterances: (3a) represents a long lag stop (Britta 1;10,23 [pʰ]); (3b), a short lag stop (Nils German 1;9,16 [b̥]); and (3c), a lead/short lag stop (Nils Spanish 1;8,28 [b]). The VOT values for target voiced stops presented later refer to lag-time measures and only lag values were used in the statistical analysis. Lead values are not provided, because the numbers of items containing lead voicing were very low.

The VOTs of a subset of words (n = 92) were re-measured by a second examiner. Inter-examiner re-measures produced a Pearson r correlation coefficient of .97 and a mean difference of 3.7 ms, indicating good inter-examiner reliability.

Results and discussion

Language dominance

Before we proceed to an analysis of the VOT results, we first provide an approximate indication of language dominance in the bilingual children.[8] Table 2 presents the percentages of utterances, produced in German and Spanish sessions, respectively, that represented the target language of the recording session. Mixed and ambiguous[9]

[7] Some studies have claimed that even in absolute initial position spirants may appear instead of voiced stops dialectally (Macken and Barton, 1980). This could provide one more reason for the scarce appearance of voiced stops initially. In the case of Nils, his mother speaks Chilean Spanish, which is is known for its high amount of spirantization, spirants being produced with much opening of the articulators and appearing in more contexts than in Standard Spanish.

[8] We are well aware that determining language dominance in bilingual children is a complex issue that cannot be decided on the basis of one or two measures (Genesee, Nicoladis and Paradis, 1995). We use the percentage of utterances (German, Spanish, mixed) per session as an approximate estimate of language dominance or preference. It has been pointed out that the use of the 'wrong' language in a session may be a symptom of the need to fill in a certain lexical gap (Genesee, Nicoladis and Paradis, 1995, p. 614), but it can just indicate preference for a certain word of the other language, without necessarily indicating a lexical gap. We also use the comparison of MLU in each language as an indication of language dominance in the sense of (syntactic) proficiency.

[9] Mixed Utterances are those utterances which contain both German and Spanish words (e.g. *otro Marienkäfer* 'other (Sp.) beetle (Ger.)'); Ambiguous Utterances are those which contain a target word which could be counted as either German or Spanish (e.g. *Mandarine* (Ger.)/*mandarina* (Sp.) 'mandarine').

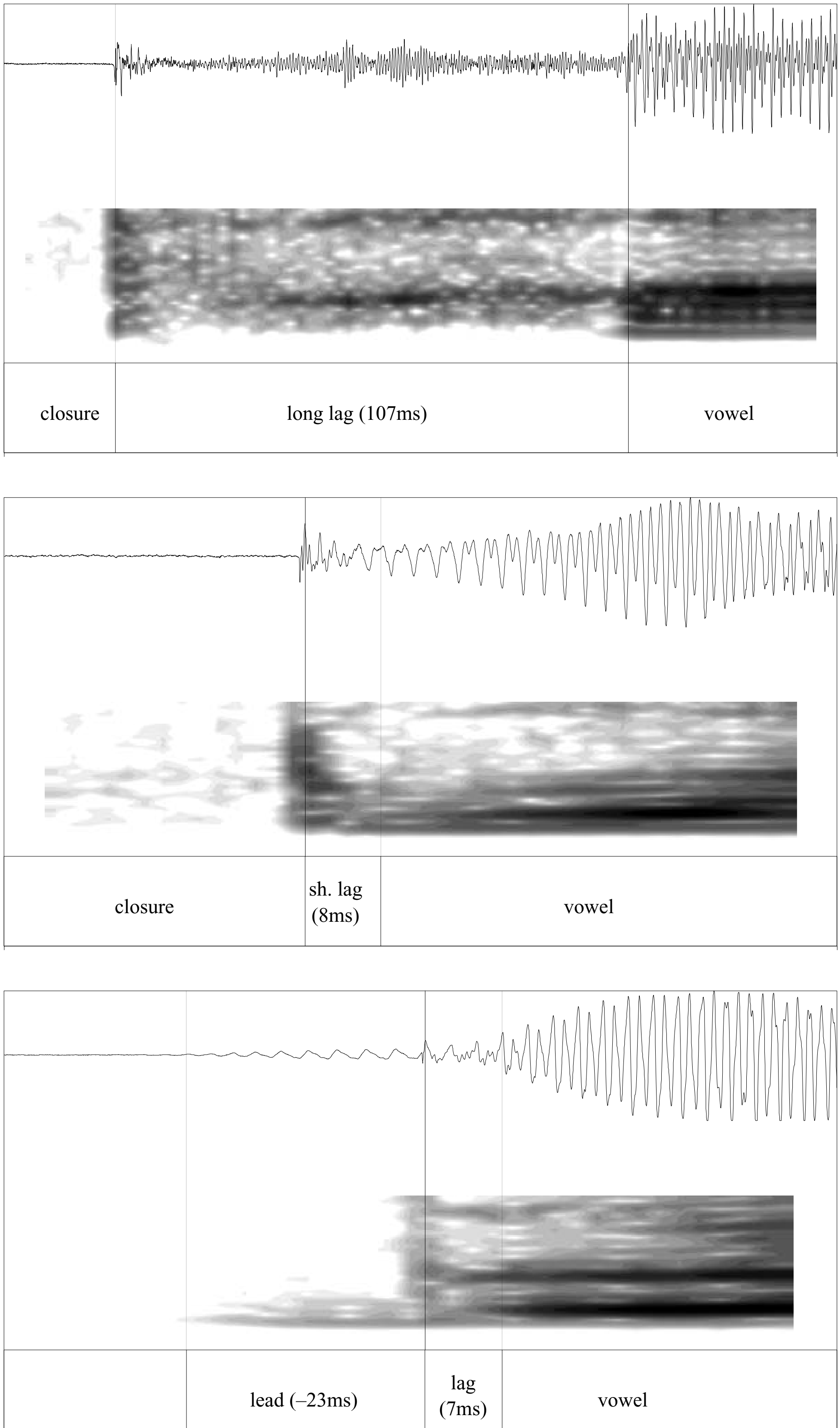

Figure 3. Acoustic display (waveform and spectrogram) illustrating VOT measurement: (3a) represents a long lag stop (Britta 1;10,23 [p^h]); (3b), a short lag stop (Nils German 1;9,16 [b̥]); and (3c), a lead/short lag stop (Nils Spanish 1;8,28 [b]).

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Table 3. *MLU in German and in Spanish for the bilingual children at some selected points.*

Child	Robert (2;3)	Stefan (2;3)	Simon (2;2)	Nils (2;2)
MLU_{Ge}	1.67	1.85	1.55	2.24
MLU_{Sp}	1.33	1.97	1.44	1.41

utterances were excluded, as were frequent vocative and greeting forms. Only those sessions that were analyzed in the VOT study were included.

Table 2 indicates that two of the children (Simon and Stefan) produced the target languages most of the time in the recording sessions whereas two of the children (Robert and Nils2) produced predominantly German in the German sessions, but both German and Spanish in the Spanish sessions. For example, in addition to the Spanish utterances (43%), Robert produced a high percentage of German (42%) and mixed/ambiguous utterances (15%) in his Spanish sessions. Similarly, Nils2 (2;3–2;6), apart from Spanish (60%), produced German 32% of the time, and mixed/ambiguous utterances 8% of the time. These results support the general impression of the investigators that Simon and Stefan were 'balanced' bilinguals, whereas Robert and Nils (after the age of 2;3) were dominant in German. A comparison of the children's Mean Length of Utterances (MLUs) at 2;2 to 2;3 leads to similar results (see Table 3). MLU values for Stefan and Simon were very similar in both languages, whereas those for Robert and Nils were higher in German than in Spanish. We return to these 'dominance' profiles later in our discussion of the VOT findings.

VOT findings

The current analysis reports individual rather than group results, because of the great deal of variability in VOT values across subjects. The monolingual data were analyzed with a two-factor Analysis of Variance (ANOVA), in which the two factors were Voice (+voice, −voice) and Place of Articulation (labial, coronal, and dorsal). The bilingual data were analyzed with a three-factor ANOVA, in which the third factor was Language (Spanish, German). Tukey HSD multiple comparisons were used to test pairwise differences. Because of missing data, a complete three-factorial design could not be conducted at all time periods for the bilingual subjects. In these cases, a two-factor ANOVA was conducted and pairwise comparisons were determined through separate t-tests. Those cases are noted in the text. We commence with the monolingual findings.

Monolingual German

Figure 4 presents the mean VOT values for stop consonants produced by the three monolingual German children.[10] The results are also given in Appendix A, along with additional summary information (standard deviation, range, and number of items with pre-voicing). Britta and Thomas's VOTs were measured at one time period (1;9–2;0), whereas Bernd's were measured at two time periods (2;0–2;3; 2;3–2;6). The results reveal that Britta and Thomas already produced stop consonants according to the expected long lag–short lag contrast in the time period 1;9–2;0. The mean VOT values for voiceless stops, averaged across place of articulation, were 75 ms for Britta and 65 ms for Thomas. ANOVAs indicated highly significant main effects for Voice in the case of both children (Britta: $F(1) = 58.25$, $p < 0.001$; Thomas: $F(1) = 98.85$, $p < 0.001$) and Tukey tests revealed that both children produced voiceless stops with significantly longer VOTs than voiced stops at all places of articulation (Britta: /p/ vs. /b/ $p < 0.001$; /t/ vs. /d/ $p < 0.05$; /k/ vs. /g/ $p < 0.001$; Thomas: /p/ vs. /b/ $p < 0.001$; /t/ vs. /d/ $p < 0.001$; /k/ vs. /g/ $p < 0.001$). The third child, Bernd, did not produce target-like VOT values until 2;3–2;6. At the earlier time period (2;0–2;3), an ANOVA indicated a significant main effect of Voice ($F(1) = 9.33$, $p < 0.01$) but Tukey tests revealed that only target /p/s were produced with significantly longer VOTs than target /b/s ($p < 0.01$). At the later time period, Bernd produced target voiceless stops with adult-like values and Tukey tests revealed significant VOT differences at both places of articulation (/p/ vs. /b/ $p < 0.01$; /t/ vs. /d/ $p < 0.001$). Also apparent in the monolingual German productions was the occasional presence of lead voicing. It occurred in 11% (12/107) of productions of target voiced stops.

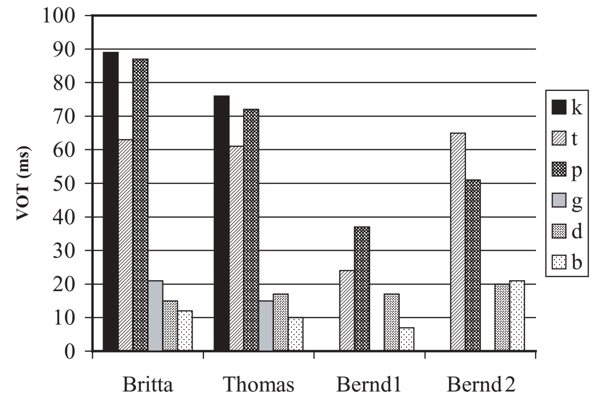

Figure 4. VOT values for three monolingual German children.

Interestingly, the children did not show the expected increase in VOT as place of articulation moved from anterior to posterior in the mouth (labial to dorsal). The main effect for Place of Articulation was non-significant in

[10] Bernd substituted dorsal with coronal stops during the analysis periods and thus Place of Articulation (dorsal) cannot be analyzed.

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the case of all three children. In particular, Britta, Thomas, and Bernd1 produced target /p/s with longer VOTs than target /t/s, a pattern that was observed later with some of the bilingual children. We have no explanation for the lack of systematic Place effects except to note that it reveals that two-year-old children have not yet acquired full control over the finer aspects of voicing. The purpose of this paper is not to analyze these aspects and, therefore, we will give no further discussion to the influence of Place of Articulation on VOT. Nevertheless, we maintain this variable in the remainder of our data analyses, given that it is a potential factor in VOT.

Bilingual German-Spanish

The following figures (Figures 5–8) present the VOT findings for the four bilingual children: Robert, Stefan, Simon, and Nils. These graphs show mean VOT scores for each place of articulation, separated according to time period and target language. The results are also reported in Appendix B, along with additional summary information. It is important to keep several questions in mind when examining the bilingual VOT findings:

1. Is there a voicing opposition in either or both languages?
2. Are the VOT values target-like? and, consequently,
3. Is there VOT differentiation according to target language?

As mentioned in the introduction, we anticipate target-like VOT values for German but not necessarily for Spanish. The results fall into two main patterns according to whether target-like VOT values were acquired in German. The first is exemplified by the findings of Robert and Stefan; the second, by Simon and Nils. Although none of the children has yet acquired the Spanish voicing contrast, the results can be further classified according to whether some voicing contrast is made in Spanish, and according to whether the languages are distinguished as regards VOT. By these criteria, results cross-classify in ways that will be discussed below: Stefan and Nils realize a certain voicing contrast in Spanish; Simon and Nils differentiate the two languages based on the VOT values of target voiceless stops.

Pattern 1: German voicing system not acquired

The first pattern is that the German voicing system (short lag vs. long lag) is not acquired. We report VOT measures for Robert in the period 2;0–2;4, this being the last time period recorded for this child. As can be seen from Figure 5, Robert produced German stops with VOTs similar to Spanish ones, realizing all stops with mean values in the short lag region (or in the region slightly beyond short lag). An ANOVA indicated that the main effects of Language $(F(1) = 0.277,\ p > 0.05)$ and Voice $(F(1) = 2.18,\ p > 0.05)$ and the Interaction Language*Voice $(F(1) = .95,\ p > 0.05)$ were not significant.

Thus, in terms of the three questions posed above, Robert results indicate the following pattern 1. No voicing opposition in German or in Spanish; 2. Non target-like phonetic realization of voicing in German and Spanish; and 3. No differentiation between the VOT values of German and Spanish.

In the case of Stefan, we report VOT results at two time intervals through to the age of three years (see Figure 6). In the first time interval (2;3–2;6), Stefan has not acquired a voicing opposition in either German or Spanish. He does, however, produce significantly greater VOTs in German than in Spanish (compare overall values: German Mean = 39 ms; Spanish Mean = 26 ms). An ANOVA indicated that the main effect of Language $(F(1) = 6.19,\ p < 0.05)$ was significant but not the one of Voice $(F(1) = 2.15,\ p > 0.05)$ nor the Interaction Language*Voice $(F(1) = 0.004,\ p > 0.05)$. In the second interval (2;9–3;0), a different pattern was evident: the main effect of Voice $(F(1) = 17.47,\ p < 0.001)$ was

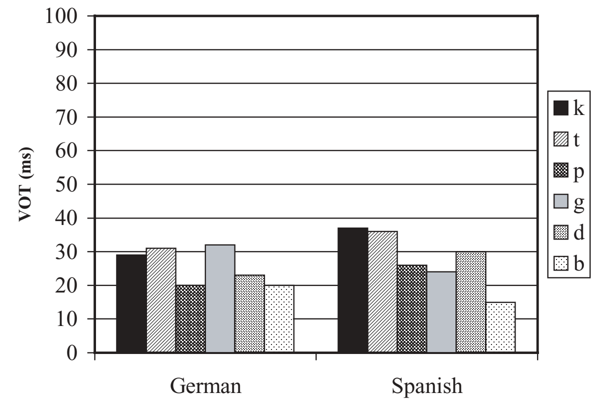

Figure 5. VOT values for the bilingual child Robert.

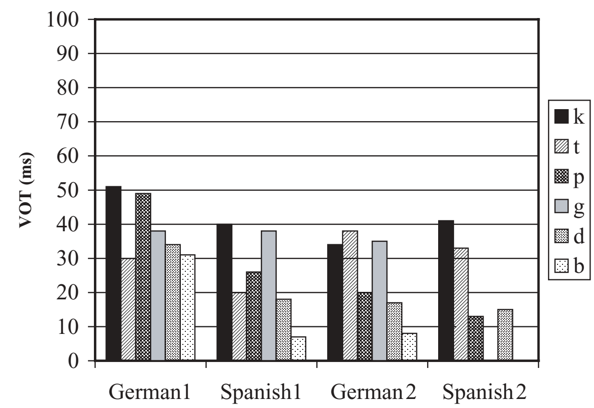

Figure 6. VOT values for the bilingual child Stefan.

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significant but not the one of Language ($F(1) = 0.53$, $p > 0.05$). Independent t-tests (a three-factor design could not be completed here) indicated that Stefan produced voiceless stops with significantly longer VOTs than voiced stops at the labial and coronal places of articulation in German (/p/ vs. /b/ $t(12) = 2.89$, $p < 0.05$; /t/ vs. /d/ $t(25) = 3.77$, $p < 0.01$), and at the coronal place of articulation in Spanish, the only place of articulation able to be tested in Spanish due to missing items (/t/ vs. /d/ $t(12) = 3.17$, $p < 0.01$). Statistical tests indicated no significant differences between languages, however. That is, even at three years, the voicing contrast was made similarly in both languages. Furthermore, voiced stops were rarely produced with lead voicing in Spanish.

In sum, Stefan's results indicate the following pattern: 1. The beginnings of a voicing opposition in German and Spanish at the second time interval; 2. Non-target-like realization of voicing: German stops were not produced with the expected long lag–short lag contrast (i.e. voiceless stops were not produced as long lag), nor were Spanish stops produced with the lead–short lag contrast; and 3. Some differentiation between the VOT values of German and Spanish at time interval 1 (as suggested by a significant main effect of Language) but not at time interval 2.

Pattern 2: German voicing system acquired

The second main pattern – we observed in the data – is that the German voicing system is acquired. This pattern is evident in the VOT values of Simon at the second time period (2;3–2;6) (see Figure 7). At the first time period (2;0–2;3), Simon's results were similar to those of Robert's in revealing no significant VOT differences either between languages ($F(1) = 3.00$, $p > 0.05$) or voicing categories ($F(1) = 3.45$, $p > 0.05$). Simon's VOT patterns underwent a significant change between the first and second time periods. In the second period (2;3–2;6), Simon produced target voiceless stops with target-like values in German. The mean VOT averaged across place of articulation was 75 ms. The presence of a voicing contrast in German was confirmed by an ANOVA indicating a significant main effect of Voice ($F(1) = 44.59$, $p < 0.001$). The ANOVA also showed a significant main effect of Language ($F(1) = 54.31$, $p < 0.001$), as well as a significant Interaction Language*Voice ($F(1) = 36.11$, $p < 0.001$), the latter result indicating that Simon realized voicing differently in German than in Spanish. Tukey multiple comparisons revealed significant differences between the VOTs for voiceless and voiced stops in German at all places of articulation (/p/ vs. /b/ $p < 0.01$; /t/ vs. /d/ $p < 0.001$; /k/ vs. /g/ $p < 0.001$) and between the VOTs for German and Spanish voiceless stops at all places of articulation (/p_{Ger}/ vs. /p_{Sp}/ $p < 0.05$; /t_{Ger}/ vs. /t_{Sp}/ $p < 0.001$; /k_{Ger}/ vs. /k_{Sp}/ $p < 0.001$). The differences between Spanish voiceless and voiced stops were non-significant, as were the differences between Spanish and German voiced stops. Simon did not produce Spanish stops with lead voicing, with the exception of occasional pre-voicing in labial stops at time period 1. He produced pre-voiced stops occasionally in German as well.

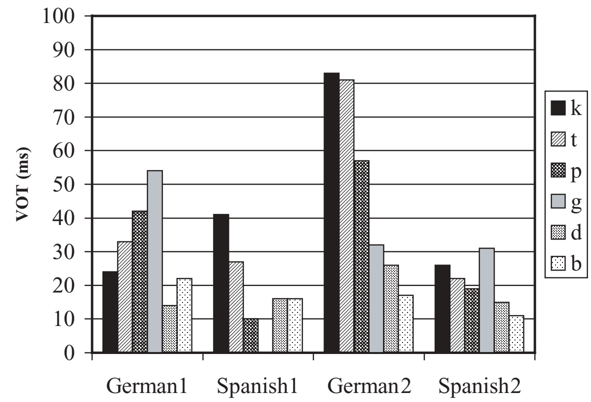

Figure 7. VOT values for the bilingual child Simon.

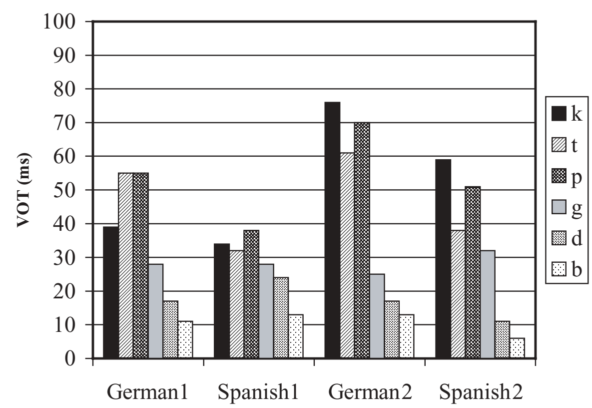

Figure 8. VOT values for the bilingual child Nils.

Thus the following pattern emerges for Simon at time period 2: 1. A voicing opposition in German but not one in Spanish; 2. The presence of target-like voicing features in German as indicated by the presence of long lag stops; and, consequently, 3. Differentiation between the VOT values of German and Spanish.

Nils also acquired long lag stops in German by the end of the testing period; however, his pattern of VOT acquisition was different from that of Simon's (see Figure 8). We report Nils's VOT values across two time periods: (1) 2;0–2;3; and (2) 2;3–2;6. An ANOVA conducted at time period 1 indicated a significant main effect of Voice ($F(1) = 30.56$, $p < 0.001$), a non-significant main effect of Language ($F(1) = 2.60$, $p > 0.05$), and a significant Interaction Language*Voice ($F(1) = 5.17$, $p < 0.05$). Although the main effect of Language was not significant, the significant interaction suggests some degree of differentiation between German and Spanish.

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Voiced stops were produced with relatively similar VOT values in both languages but voiceless stops were produced with higher VOTs in German than in Spanish (German voiced Mean = 17 ms; Spanish voiced Mean = 21 ms; German voiceless Mean = 50 ms; Spanish voiceless Mean = 35 ms). Tukey tests indicated significant voicing oppositions in German at the labial and coronal places of articulation (/p/ vs. /b/ $p < 0.01$; /t/ vs. /d/ $p < 0.01$) but not in Spanish at any place of articulation.

Although Nils had started to differentiate the voicing systems of German and Spanish at time period 1, his VOT values are not yet target-like. He produced German voiceless stops with mean values lower than expected (50 ms).[11] Furthermore, he produced German voiced stops with lead voicing: 31% (11/35) of German target voiced stops were produced with lead voicing, a greater percentage than in Spanish, in which, at the same time period, only 19% (5/26) were produced with lead voicing. The former percentage is also significantly higher than the one observed in the monolingual German children ($\chi^2(1) = 7.94$ $p < 0.01$).

At time period 2 (2;3–2;6), an interesting development occurred in Nils's VOT values. He produced German voiceless stops with a mean VOT value of 70 ms, a value consistent with the expected long lag range; however, he produced Spanish voiceless stops with a mean value of 50 ms, a value greater than at the previous time period (Mean = 35 ms) and longer than the expected short lag range. That is, Spanish voiceless stops have now become 'less Spanish'. Nevertheless, other aspects of Nils's VOT development have matured. An ANOVA indicated significant main effects of Language ($F(1) = 5.56$, $p < 0.05$) and Voice ($F(1) = 96.49$, $p < 0.001$) suggesting maintenance of the voicing opposition and some degree of differentiation between the two languages. A non-significant or only marginally significant Interaction Language*Voice ($F(1) = 3.53$, $p < 0.06$) suggests, however, that the voicing opposition is realized similarly in the two languages: Both German and Spanish voiceless stops are produced with high VOT values. Tukey comparisons revealed that Nils has acquired a significant voicing opposition in German across all places of articulation (/p/ vs. /b/ $p < 0.001$; /t/ vs. /d/ $p < 0.05$; /k/ vs. /g/ $p < 0.001$) and in Spanish across the labial place of articulation (/p/ vs. /b/ $p < 0.01$). His VOT values for German voiceless stops, as mentioned above, have become more target-like and German voiced stops are less frequently produced with lead voicing (10% or 3/30). Spanish voiced stops are not produced with lead voicing, with the exception of labial stops (44% or 4/9, considering labials only).

[11] Nils's mean VOT for target voiceless stops at time period 1 is consistent with the mean values reported for adult subjects in German (Braunschweiler, 1997). Generally, longer VOTs for target long lag stops are reported for two-year-old children.

Table 4. *Summary of bilingual VOT patterns according to voice and language differentiation.*

Child	Differentiation across voice	Target-like acquisition of voicing	Differentiation across language
Robert	No	No	No
Stefan 1	No	No	Yes (mild)
2	Yes (Ger, Sp)	No	No
Simon 1	No	No	No
2	Yes (Ger)	Yes (Ger)	Yes
Nils 1	Yes (Ger)	No	Yes
2	Yes (Ger, Sp)	Yes (Ger)	Yes

In sum, Nils's VOT development by time period 2 may be summarized as follows: 1. The beginnings of a voicing opposition in both German and Spanish; 2. The presence of target-like voicing in German but not in Spanish: Spanish voiceless stops were produced with higher than expected VOT values and voiced stops were not generally produced with lead voicing; and 3. Some differentiation between the VOT values of German and Spanish.

The VOT patterns of the four bilingual children are summarized in Table 4 according to the three main findings: 1. Differentiation with respect to voicing category; 2. Target-like realization of voicing; and 3. Differentiation with respect to target language.

Influence of language dominance

The above analysis indicated a great deal of variation in the way VOT was acquired by individual bilingual children. We now consider the influence of language dominance on VOT realization by returning to the information presented above in Tables 2 and 3, based on a count of utterances per session and MLU. The data in these tables suggest that two children (Simon and Stefan) were relatively balanced in their use of German and Spanish, whereas two children (Nils and Robert) were dominant in German. However, if we compare these dominance patterns with the VOT results, we observe no clear correlation between the two sets of results. For example, Simon, who was a 'balanced' bilingual, produced target-like VOT values in German by 2;3–2;6, but Stefan, who was also 'balanced', did not produce target-like values in German even by the age 2;9–3;0. Similarly, Robert, who was German dominant, did not acquire target-like voicing in German, whereas Nils, also German dominant, produced VOT values in German that approached adult-like norms. Nevertheless, Nils's results

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at time period 2 could reflect some effect of dominance because his VOT realization in Spanish became less Spanish during the course of testing, presumably due to the influence of German. We refer to this finding later on in the general discussion.

General discussion

This study examined VOT development in a group of young monolingual German and bilingual German-Spanish children (aged 1;9–3;0). We first summarize our findings and then consider their implications for the question of cross-linguistic interaction in bilingual language development.

Our findings on VOT acquisition in three monolingual German children are consistent with previous findings on VOT development in English; that is, at around the age of two years, children acquire a target-like distinction between long and short lag stops. Two of the children (Britta and Thomas) acquired a target-like distinction by 1;9–2;0 and the third child (Bernd), by 2;3–2;6. We were unable to report findings on monolingual Spanish VOT acquisition but the literature is united in the fact that children, acquiring a voicing contrast between lead and short lag stops, do not develop an adult-like contrast by two years, rather, later than four to five years. Nevertheless, two-year-old children learning these languages may manifest a voicing distinction in other ways, particularly through making a significant VOT distinction in the short lag region.

Our findings on VOT acquisition in four bilingual German-Spanish children indicated that the effects of bilingualism were not uniform across children. If we consider acquisition of voicing in German, our results are consistent with two main patterns: two of the children (Robert and Stefan) did not acquire the German voicing system, producing target voiceless stops in the short lag region throughout the analysis period (Robert: 2;0–2;4; Stefan 2;3–3;0), whereas two of the children (Simon and Nils) acquired the German system, producing voiceless stops in the long lag range by 2;3–2;6. Turning to the voicing contrast in Spanish, none of the children produced target voiced stops with lead voicing consistently, which means that none of the children distinguished Spanish voiced and voiceless stops in a target-like fashion. However, two children, Stefan and Nils at time period 2, contrasted voiced and voiceless in Spanish by means of a solution comparable to the German contrast: they produced target voiceless stops with significantly longer VOTs than target voiced stops at some places of articulation.[12] We now consider the bilingual findings in more detail.

Cross-linguistic interaction

Our VOT findings suggest that the phonetic/phonological systems of bilingual children do not develop independently but interact. If our results had been consistent with completely independent systems, we would have expected the bilingual children to have acquired a target-like voicing contrast in German by approximately two years of age and to have produced Spanish stops predominantly in the short lag region. This was found to be the case in one child only (Simon). Whereas we grouped the VOT results above in terms of acquisition of the German voicing system, we now consider the findings in terms of the effects of bilingualism on the development of voicing. We also take into account the development of the Spanish voicing system. Specifically, our results are consistent with three different patterns: Delay, Transfer, and No cross-language influence.

Delay

The bilingual situation may lead to delay in the target-like phonetic realization of voicing in German. Robert's and Stefan's VOT patterns (cf. Figures 5 and 6) are consistent with an early stage in the acquisition of VOT, in which stops are produced mainly in the short lag region. Reviewing the stages of VOT acquisition shown earlier in Figure 2, Robert appears to be situated at stage 1, because he makes no voicing opposition, and Stefan at stage 2, because he makes a significant voicing opposition, albeit not target-like and not at all places of articulation. It could be possible to interpret this slower acquisition not as delay but simply as individual variation. Although this may be the case for Robert, who was tested only until 2;4 (note Bernd did not acquire target-like VOTs in German until 2;3–2;6), this argument would be difficult to sustain for Stefan who was tested through to 3;0 years. In Spanish, Stefan makes a timid voicing contrast at time 2, which places him at the same VOT stage as many Spanish monolinguals of the same age. He does not, however, differentiate stops according to target language.

Transfer

Rather than delay in the phonetic realization of voicing, transfer of voicing features from one system to another may take place. Two potential examples of transfer occur in Nils's data. At time period 1, Nils produced a higher proportion of target voiced stops with lead voicing in German than would have been expected in the monolingual situation (compare: 31% production of lead stops by Nils vs. 11% productions of lead stops by monolingual German children). At time period 2, Nils produced many target voiceless stops with aspiration in

[12] It is possible that the bilingual children may be using other means, apart from VOT, to make a distinction between target voiced and voiceless stops in Spanish, for example, through spirantization of target voiced stops. Additional analyses of the data would need to be conducted to determine if this is the case.

Spanish, resulting in mean VOT values that were greater than the expected short lag range. Thus, Nils's patterns could be consistent with transfer of lead voicing features from Spanish into German at time period 1, and transfer of long lag voicing features from German into Spanish at time period 2.

Concerning transfer of lead voicing, it seems puzzling that Nils chooses to use lead stops when they are marked forms and are generally acquired late. One possibility is that Nils is seeking to form the greatest acoustic opposition possible between voiceless and voiced stops. Because his productions of target German voiceless stops are still not target-like (many are produced as short lag), the use of lead voicing in voiced stops allows him to make an opposition. Nevertheless, Nils is not producing many pre-voiced stops in Spanish making the case for transfer of lead voicing less likely. It should be noted that similar situations have been reported in the bilingual literature on VOT (Williams, 1980; Heselwood and McChrystal, 2000). For example, Heselwood and McChrystal (2000) found that Panjabi-English bilingual children (aged approximately 10 years) produced a high proportion of English voiced stops with lead voicing despite the fact that the same subjects did not consistently produce lead voicing in their Panjabi voiced stops. Thus, there appears to be a certain lack of systematicity in the use of lead voicing by bilingual children, evident both in the Panjabi-English children's and in Nils's productions.

An alternate explanation of the finding is that Nils is exposed to German spoken with a Spanish accent (from his Spanish-speaking mother), in which voiced stops are produced with lead voicing. Thus, the voicing characteristics of the input may play a role in explaining the findings. To test this possibility we would need to conduct additional analyses of the data in which the VOT characteristics of the mother's speech are also measured. Nevertheless, this explanation may not be sufficient to account for the results, because not only Nils but the other three children would have been exposed to German spoken with a Spanish accent; yet, only Nils produced a significant number of German stops with lead voicing.

Concerning the transfer of long lag voicing features, dominance factors may account for these findings. As of 2;2 years, Nils has been becoming less bilingual due to participation in German Kindergarten and due to the fact that he is spending less time at home with his Spanish-speaking mother, his main source of Spanish. He still maintains a distinction between German and Spanish (as determined by statistical tests), but many of his Spanish voiceless stops are now produced with high VOT values such that they resemble German stops. This finding is similar to Johnson and Wilson's (2002) finding with two Japanese-English bilingual children (aged 2;11 and 4;11) growing up in Canada. These children also produced Japanese voiceless stops with long lag VOT values, although in their cases, the mean VOTs were longer than those recorded here, and statistical tests showed that only the older child distinguished English and Japanese voiceless stops on the basis of VOT. Unfortunately, we do not have any additional VOT information (at present) to know whether Nils continues to maintain a VOT distinction between German and Spanish, or whether his Spanish voicing characteristics will become even more German-like, akin to the patterns of the two Japanese-English children.

No cross-language influence

Finally, there may be no influence between languages in the phonetic realization of voicing. In our study this was evident in the VOT development of Simon who acquired a long lag–short lag contrast in German by 2;3–2;6 and who produced Spanish stops predominantly in the short lag region. It is true that Simon's VOT development in German, compared with two of the three monolingual German children, was slightly late, and that his patterns in Spanish showed no sign of a voicing opposition, nor of the consistent use of lead voicing. Thus, a case could be made for a slight delay effect due to bilingualism. However, given that one of the German monolingual children (Bernd) did not manifest long lag stops until 2;3–2;6 and that there is considerable variability in the way young children mark a voicing distinction in a language that contains the short lag–lead distinction (Macken and Barton, 1980), we prefer not to interpret Simon's results as delay, but rather as individual variation. His profile resembles that of the bilingual child studied by Deuchar and Clark (1996), Manuela, who did not display target-like voicing characteristics in English at 1;11 but did by 2;3. Similar to Manuela, he exhibits the beginnings of a voicing distinction in Spanish by producing target voiceless stops with slightly longer VOTs than target voiced stops at two places of articulation (labial and coronal); unlike Manuela, however, his VOT values in Spanish (voiced and voiceless stops) are lower. In Simon's case, the occurrence of transfer could have been expected in his Spanish, given that his parents report that their common language at home is Spanish and given that Simon's father speaks with a clear non-native accent in Spanish. That is, Simon is exposed to long lag stops in his father's Spanish, and nevertheless, his VOT patterns displayed no evidence of transfer.

The preceding discussion summarized the main patterns of VOT acquisition in the bilingual subjects. Another important aspect of the results is the fragile nature of the VOT patterns across time. This conclusion is suggested by the VOT profiles of two of the children, which did not follow typical developmental trends. Stefan's VOT patterns at time period 1 pointed to an early distinction between German and Spanish (as suggested by significantly higher overall VOT values in German), but this distinction was no longer evident at time period 2. Similarly, Nils' VOT patterns became less rather than more target-like in Spanish during the testing period. A more complete understanding of the effects of bilingualism on VOT development would require follow-up testing on the same group of children during the course of childhood to document changing patterns of VOT acquisition and to determine the ultimate attainment of voicing.[13]

Our finding of cross-linguistic interaction in VOT joins recent findings in other areas of bilingual phonetic/phonological development, which point to interaction, notably, in syllable structure, prosodic word shape, vowel length contrast, and certain aspects of segmental development (Paradis, 2000; Kehoe, 2002; Keshavarz and Ingram, 2002; Lleó, 2002; Lleó, Kuchenbrandt, Kehoe and Trujillo, 2003). A central focus of this research has been to determine when and in what direction interaction takes place. Possible explanations for cross-linguistic interaction include the presence of structural ambiguity in the input (Müller and Hulk, 2000; Paradis, 2000), differences in the frequency of the target phenomena in the respective languages, and markedness (Lleó, 2002). In particular, markedness may be relevant in explaining the VOT findings. We hypothesize that the acquisition of marked or complex phenomena requires a certain amount of quantitative evidence. Marked phenomena that appear in one of the languages only, such as long lag stops in German and lead stops in Spanish, will be diluted in their quantitative strength due to the bilingual situation, and hence require more time to be acquired by the bilingual child. Although cross-linguistic interaction has been documented in several phonological areas, we speculate that VOT may be one area in the phonetic/phonological domain that is particularly susceptible to interaction. Being predominantly a phonetic skill and having to do with timing coordination that tends to be automatic, may explain its specific vulnerability to interaction effects. The L2 literature suggests that even when adults have acquired many phonological aspects of a second language, they may never acquire target-like VOT values in that language. That is, such phonetic skills require a long time to consolidate, but once they are automatized, they are very robust and only relatively permeable to the influence of a foreign language.

Finally, our findings showed that two of the children (Robert and Stefan2) did not differentiate the voicing systems of German and Spanish on the basis of VOT. This result could potentially support the claim that bilingual children initially have access to a single voicing system that differentiates into two systems only later in development (e.g. Volterra and Taeschner, 1978). We would be reticent to make this claim, however, given what we know of early VOT development. Acquisition of voicing is generally characterized by an initial stage in which all stops are short lag regardless of the target language. Therefore, we are unable to distinguish, in this instance, a single non-differentiated system from the initial stages of voicing in the two target languages. This point gives credence to the fact that great care should be taken in bilingual research to interpret results within the developmental framework of the respective languages that are being acquired.

Language dominance and modularity

German-Spanish bilingual children have to cope with a tri-partite VOT distinction, of which two of the three members (long lag and lead) are marked. Short lag stops are present in both languages, which means that they are more frequent in the input than long lag and lead stops. Whether delay in the case of Stefan (and Robert, if we were to interpret his data as showing some delay, too) is due to markedness (the markedness of long lag stops with respect to short lag stops) or to input frequency (the higher frequency of short lag stops with respect to long lag stops) is difficult to ascertain; but in any case, delay has its origins here in bilingualism, because the bilingual child has to master a tri-partite VOT distinction and not a bi-partite one as the monolingual. Monolingual children also initially produce the unmarked term of each opposition, i.e. short lag stops, both in the German short lag–long lag and in the Spanish short lag–lead opposition; however, some bilingual children keep the unmarked term of the opposition to the exclusion of the marked terms longer than the monolinguals, as in the case of Stefan and to a certain degree Robert. Language dominance or preference appears to play no visible role, given that one of the children, Robert, is German dominant, and the other, Stefan, is balanced. However, as our study shows, bilingualism does not necessarily lead to delay or to transfer: one of the children, Simon developed a target-like voicing opposition in German and the beginnings of a contrast for labials and coronals in Spanish by 2;6. Notice that Simon is considered to be the most balanced child in our study, which might indicate that 'balance' is a necessary condition for the relatively autonomous phonological development of two languages. In contrast, another child, Nils, is clearly dominant in German. His German VOT patterns are similar to those of monolingual German children, whereas his Spanish VOT patterns show an influence from German. Interestingly, Nils introduces a voicing contrast into

[13] A follow-up study of VOT in early childhood is currently under way in the extension of the project 'Prosodic constraints on the phonological and morphological development of bilingual acquisition' at the Research Centre on Multilingualism, University of Hamburg, under the direction of Conxita Lleó (supported also by the DFG).

Spanish (long lag vs. short lag), which is not available to Spanish monolingual children. Because this contrast is not the target one, it may be interpreted as transfer. On the other hand, it can be argued that bilingualism has an advantageous effect in that it allows this child to make a contrast that is not available in the monolingual context; that is, it has the bootstrapping effect proposed by Gawlitzek-Maiwald and Tracy (1996), according to which, 'something that has been acquired in language A fulfills a booster function for language B' (Gawlitzek-Maiwald and Tracy, 1996, p. 903). As these authors put it, the 'bootstrapping metaphor avoids the negative connotations often associated with terms like interference or transfer and underscores the resourcefulness of the bilingual child' (ibid., p. 901). In Nils' productions, the contrastive distance between the two languages is reduced in favor of a contrast (long vs. short lag) that is not as difficult as the target-like contrast of Spanish (short lag vs. lead).

Our data, thus, show that the dominant language will tend to influence the other language in early bilingual acquisition, as it has often been proposed (Genesee, Nicoladis and Paradis, 1995). This pattern is evident in Nils's data. However, balanced bilinguals may also show the influence of one language on the other, as is the case with Stefan. We have to keep in mind that these very young children have not completed the acquisition task. Their incomplete systems may be susceptible to the influence of the other language; this being one of the basic characteristics of bilinguals, not available to monolinguals. Genesee, Nicoladis and Paradis (1995, p. 624), who also found cross-language influence in the case of balanced bilinguals, argue that 'they made use of whatever resources they had available in both languages'.

Finally, the modularity of language should be emphasized. By that we not only refer to the specialization of brain areas for language, but to its specialization for the various components of grammar (see e.g. Fodor, 1983; Smith and Tsimpli, 1995; Chomsky, 1996). There is no reason to believe that different components of grammar, such as syntax, morphology, phonology, and their interfaces all develop at the same pace. This view implies that lexical inventory, syntactic proficiency as measured by MLU, morphological proficiency, and phonological/phonetic proficiency need not converge at all points of development. To what extent these measurements converge, and under what conditions they tend to diverge will have to be elucidated by future research. Measurements for phonological and phonetic proficiency have received less attention from a bilingual perspective (but see Ingram 2002), and the impression emerges from the present study that a) such measurements will be very helpful in bilingual research; and b) VOT deserves a place in such a catalogue of measurements.

Summary and conclusion

An analysis of the VOT patterns of four bilingual children (aged 2;0–3;0) reveals the following three main findings: 1. Bilingual input influences the acquisition of the voicing contrast but its influence is not uniform across children; 2. Different patterns of VOT acquisition across children cannot be fully explained by language dominance; and 3. The voicing systems of young bilingual children are fragile and subject to change. Our findings are consistent with recent claims in bilingual research that the phonetic/phonological systems of bilingual children do not develop autonomously but interact.

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Appendix A: ***Summary of monolingual German VOT values (in ms).***

Child (age)	Stop	n	Mean VOT	VOT range	SD	Lead voicing (n)
Britta (1;9–2;0)	/p/	10	87.2	21–141	47.2	0
	/b/	11	12.4	3–23	6.3	1
	/t/	10	62.5	25–124	40.7	0
	/d/	11	15.3	8–30	8.4	2
	/k/	10	88.9	36–163	45.4	0
	/g/	10	21.3	5–37	9.2	1
Thomas (1;9–2;0)	/p/	14	72.0	27–141	38.5	0
	/b/	10	10.4	5–38	10.4	1
	/t/	14	60.7	7–125	30.6	0
	/d/	13	17.0	5–26	6.8	1
	/k/	15	76.1	52–130	22.7	0
	/g/	8	15.1	8–31	9.2	2
Bernd1 (2;0–2;3)	/p/	11	37.4	2–111	32.3	0
	/b/	10	7.2	3–13	3.4	2
	/t/	10	24	9–65	20.7	1
	/d/	11	16.9	6–27	6.6	0
Bernd2 (2;3–2;6)	/p/	13	51.0	17–78	18.4	0
	/b/	10	20.8	4–55	15.6	0
	/t/	10	65.2	17–111	28.9	0
	/d/	13	20.5	8–44	12.2	2

Appendix B: ***Summary of bilingual VOT values (in ms).***

	German					Spanish				
Stop	n	Mean VOT	VOT range	SD	lead (n)	n	Mean VOT	VOT range	SD	lead (n)
Robert (2;0–2;4)										
/p/	9	20.4	3–57	18.3	3	12	26.0	5–71	19.2	0
/b/	14	19.6	6–34	9.9	0	13	15.1	3–44	12.7	2
/t/	10	31.3	19–54	12.4	0	10	35.7	11–88	21.9	0
/d/	10	22.9	7–37	10.5	0	1	30			
/k/	15	28.8	14–64	12.0	0	14	36.6	17–115	26.3	0
/g/	5	32	26–37	5.5	0	6	24.2	17–39	8.1	0
Stefan1 (2;3–2;6)										
/p/	10	48.5	5–100	34.6	0	14	26.4	3–109	27.0	0
/b/	9	30.9	10–99	30.11	0	4	6.5	4–10	2.6	0
/t/	8	30.0	5–77	22.6	0	8	19.5	10–34	7.8	0
/d/	9	33.8	6–124	36.6	0	3	17.7	12–25	6.7	0
/k/	8	50.6	24–80	17.4	0	12	39.5	20–67	13.5	0
/g/	5	38.4	12–63	20.6	0	6	37.7	16–97	31.7	1

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Appendix B: ***Continued***

	German					Spanish				
Stop	n	Mean VOT	VOT range	SD	lead (n)	n	Mean VOT	VOT range	SD	lead (n)
Stefan2 (2;9–3;0)										
/p/	4	19.5	9–29	10.0	0	6	12.5	0–22	9.2	0
/b/	10	8.4	2–16	4.8	0	NO TOKENS FOUND				
/t/	12	37.5	6–69	17.2	0	6	32.5	21–54	12.6	0
/d/	15	17.1	6–46	10.7	1	8	15.0	8–29	8.1	0
/k/	15	33.9	21–53	10.0	0	15	40.6	17–95	21.2	0
/g/	10	34.5	16–62	14.5	0	NO TOKENS FOUND				
Simon1 (2;0–2;3)										
/p/	5	42.4	11–97	33.8	0	15	10.1	4–19	4.6	2
/b/	13	21.5	5–66	15.8	2	12	15.5	6–60	14.9	2
/t/	9	33.2	12–119	33.3	0	11	27.0	6–100	26.4	1
/d/	9	14.2	8–25	4.8	2	5	16.2	11–27	6.4	0
/k/	6	23.8	9–43	11.6	0	9	41.22	17–112	30.3	0
/g/	3	54.0	27–92	33.9	0	NO TOKENS FOUND				
Simon2 (2;3–2;6)										
/p/	9	57.1	16–97	25.5	0	14	18.8	8–47	9.6	0
/b/	10	17.4	9–32	7.8	0	8	10.7	4–23	6.2	0
/t/	11	81.0	35–158	35.4	0	9	22.0	11–47	11.1	0
/d/	10	25.8	12–73	19.7	0	8	15.2	8–21	4.6	1
/k/	11	83.4	23–123	32.1	0	15	26.1	13–76	14.9	0
/g/	7	31.7	5–73	23.3	0	6	31.2	17–58	14.6	0
Nils1 (2;0–2;3)										
/p/	8	55.1	9–96	30.3	0	15	38.3	3–72	25.7	0
/b/	14	11.3	2–72	18.3	7	9	12.9	2–35	10.7	3
/t/	11	54.8	12–118	36.2	0	9	31.6	10–82	23.3	0
/d/	15	17.5	5–55	14.5	4	9	24	10–38	9.5	2
/k/	10	39.3	14–67	19.6	0	10	33.5	18–75	16.5	0
/g/	6	28.3	7–50	15.9	0	8	28.0	10–45	11.2	0
Nils2 (2;3–2;6)										
/p/	7	69.7	36–111	24.5	0	11	50.6	13–100	28.2	0
/b/	8	13.1	7–21	5.2	0	9	5.6	2–13	4.0	4
/t/	7	60.9	29–96	30.4	0	8	38.4	13–113	32.4	0
/d/	11	16.6	6–42	9.6	3	10	11.0	7–14	2.4	0
/k/	12	76.1	45–134	27.2	0	9	59.0	20–91	21.4	0
/g/	11	25.0	10–82	20.7	0	6	32.3	16–60	17.4	0