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Development of voice onset time in monolingual and bilingual French-speaking children

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Abstract

This study examined Voice Onset Time (VOT) in monolingual and bilingual French-speaking children, aged 3 to 6 years (n = 42), and in monolingual adults (n = 15). The bilinguals consisted of those acquiring languages with a long lag – short lag (Bi – Long) and those acquiring languages with a lead – short lag contrast (Bi – Lead). We predicted differences between monolinguals and Bi – Long but no differences between monolinguals and Bi – Lead, given that children in the latter group have the same voicing contrast as French. Children and adults played a Memory game in which they produced target words containing stop consonants in word-initial position. Analyses examined the effect of bilingualism and control variables (age, place of articulation (PoA), vowel type) on positive VOT values and on the presence of lead voicing. Results indicated that monolinguals and both groups of bilinguals produced target voiced and voiceless stops with positive VOTs of similar magnitude. Nevertheless, Bi – Long children who were not dominant in French had longer VOTs than monolinguals, consistent with an influence of the L1 on French. Bi – Long children also produced marginally fewer tokens with lead voicing than monolinguals. In addition, results indicated that age, PoA, and vowel type influenced VOT.

Keywords: Voice onset time; Bilingualism; Cross-linguistic interaction; Dominance

1. Introduction

In recent years, investigators have examined the phonetic/phonological development of bilingual children and compared it to that of monolingual children in order to determine whether there is a grammatical influence between languages (Almeida et al., 2012; Bunta and Ingram, 2007; Fabiano-Smith and Goldstein, 2010a,b; Goldstein and Bunta, 2012; Keffala et al., 2018; Lléo, 2002, among many). The presence of systematic differences between monolinguals and bilinguals is suggestive of cross-linguistic interaction (Paradis and Genesee, 1996). Certain phonetic/phonological domains have predominated in bilingual research (e.g., syllable structure, rhythm), one of them being Voice Onset Time (VOT). Studies which have investigated the development of VOT in children who are acquiring their languages bilingually indicate that bilingual input may influence the development of native-like VOT values in the learners' two languages

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(Deuchar and Clark, 1996; Fabiano-Smith and Bunta, 2012; Johnson and Wilson, 2002; Kehoe et al., 2004; Khattab, 2000; Stoehr, 2018; Stoehr et al., 2018).

This study investigates the acquisition of VOT in a population of French-speaking bilingual children. Several studies have documented VOT development when one of the languages of the bilingual is English (Deuchar and Clark, 1996; Fabiano-Smith and Bunta, 2012), Spanish (Deuchar and Clark, 1996; Fabiano-Smith and Bunta, 2012) or German (Kehoe et al., 2004; Stoehr et al., 2018) but few studies have tested young French bilinguals (cf. Splendido, 2014). Furthermore, much of the research has focused on VOT acquisition when the majority language (i.e., language of the environment) is characterized by a long lag – short lag distinction, whereas this study focuses on VOT acquisition when the majority language (i.e., French) has a lead – short lag distinction. We may expect different patterns of development according to the VOT contrast in the majority language. In the *Introduction*, we provide information on VOT and its development in monolingual and bilingual children.

1.1. Voice onset time

VOT is an acoustic measure which relates the timing of vocal fold vibration to supraglottal articulation. It can be defined as the temporal relation between the release of the stop consonant and the onset of vocal fold vibration (Abramson and Whalen, 2017; Lisker and Abramson, 1964). If the vocal fold vibration occurs during consonantal closure and continues until the stop release, it is referred to as voicing lead. If the vibration occurs after the moment of release, it is referred to as voicing lag. By convention, the stop release is given a reference point of 0 ms; measurements of voicing lead have negative values and voicing lag have positive values. Short lag stops have a VOT around 0 ms or may have a very brief period of aspiration through to 30 ms. Long lag stops have a longer period of aspiration typically ranging from 30 to 80 ms.

This study focuses on VOT in French which is characterized by a lead – short lag distinction. Lein et al. (2016) summarized the findings of ten studies on the VOT of voiceless stops /p, t, k/ in French-speaking adults (including Canadian and European French) which gave values ranging from 14 to 32 ms for /p/, 18 to 35 ms for /t/ and 32 to 49 ms for /k/. Nearey and Rochet (1994) reported slightly longer values for voiceless stops (/p/: 18 to 48 ms; /t/: 21 to 49 ms; /k/: 32 to 62 ms) with significant effects for vowel height: VOT was longer when the voiceless stop consonant preceded a high vowel (e.g., /y, i, u/). They found that French adults produced prevoicing on 91% occasions with the average length of prevoicing being 96 ms. Although many authors only report values for prevoicing in target voiced stops, it is also possible to measure the noisy release following the burst (see Davis, 1995). This ranged from 7 to 9 ms for /b/, 10 to 21 ms for /d/, and 17 to 22 ms for /g/. Apart from the effect of vowel length which appears to be particularly strong in French (Nearey and Rochet, 1994), values may vary depending upon task differences (whether word vs. sentence reading is used), and whether syllable stress and speech rate are controlled (Lein et al., 2016).

1.2. Development of VOT in monolingual children

1.2.1. Long lag versus short lag

Multiple sources suggest that children acquire the distinction between short and long lag stops around the age of 2;0 to 2;6 (Davis, 1995; Kehoe et al., 2004; Macken and Barton, 1980a). According to Macken and Barton (1980a), children pass through three stages of VOT acquisition. In the first stage, children produce short lag stops in which they do not differentiate target voiced or voiceless stops. In the second stage, children again produce short lag stops but they produce target voiceless stops with significantly longer VOTs that target voiced stops. This contrast may not be perceptible to adults however. In the third stage, children realize target voiceless stops with long lag voicing and target voiced stops with short lag voicing. Initially children may overshoot the mark and produce exceptionally long VOT values for target voiceless stops. Gradual refinement and stabilization of VOT occurs later and even 6-year-olds may differ from adults in the finer temporal aspects of VOT (Lowenstein and Nittrouer, 2008; Whiteside et al., 2003).

1.2.2. Lead versus short lag

Most sources suggest that the lead versus short lag distinction is acquired later than the long versus short lag distinction (Allen, 1985; Davis, 1995; Khattab, 2000). Macken and Barton (1980b), for example, found that Spanish-speaking children, aged 3;10, were not consistently producing lead voicing whereas Khattab (2000) reported even later age ranges: two Lebanese Arabic-speaking children, aged 5 and 7 years, were not consistently producing lead voicing. Davis (1995) documented a gradual increase in prevoicing in Hindi-speaking children from approximately 45% prevoicing at 2;0 to 73% at 6;0.

Lead voicing is considered difficult because the child needs to achieve the aerodynamic conditions necessary to ensure vocal fold vibration while the oral cavity is sealed off by stop closure (Kong et al., 2012). The child needs to lower the supra-glottal air pressure relative to the sub-glottal air pressure by enlarging the supra-glottal volume, for example, by lowering the larynx or elevating the soft palate. This requires motor coordination.

Not all studies have reported late acquisition of VOT in children, however. MacLeod (2016) indicated percentages of lead voicing as high as 69% in Canadian French monolingual children, aged 2,6 to 4;6. Okalidou et al. (2010) also found that children learning standard Greek acquired adult-like values of lead voicing as early as 2;0 to 2;6. In the case of Greek, children counteract the difficult aerodynamic forces by allowing nasalization during the stop closure (Okalidou et al., 2010).

In studies where children do not acquire lead voicing, authors report that children may still make a distinction between target voiced and voiceless stops. Macken and Barton (1980b) found that Mexican Spanish-speaking children produced target voiced stops as spirants not only in utterance-medial position, which is typical of Spanish, but also in utterance-initial position. They produced stops for target voiceless stops and fricatives for target voiced stops. Allen (1985) observed that French-speaking children resolved the ''pre-voicing problem'' by realizing their voiced stops in non-initial fully voiced contexts. The children used continuous voicing in place of negative VOT for a large majority of voiced targets (i.e., 65%). MacLeod (2016) also found this to be the case in her study of Canadian French-speaking children. Children continued voicing from the previous word to the target word in up to one half of the productions. Nevertheless, the frequency with which children employed continuous voicing was similar across target voiced and voiceless stops, suggesting that continuous voicing was not a unique strategy reserved for target voiced stops alone.

1.3. Development of VOT in bilingual children

Studies which have compared the VOT patterns of monolingual and bilingual children have reported differences between the two groups consistent with cross-linguistic interaction. That is, the act of acquiring the timing relations between supraglottal articulation and glottal vibration in one language influences the way that these timing relations are acquired in the other language. We organize our discussion of findings according to whether the majority language is characterized by a long lag versus short lag or lead versus short lag distinction. See Lee and Iverson (2012) for a study focusing on bilingual children, who are acquiring a language (i.e., Korean) which is characterized by a three-way distinction.

1.3.1. Majority language: long lag versus short lag

Several patterns of cross-linguistic interaction have been identified in bilingual children who are acquiring a majority language with a long versus short lag distinction (Deuchar and Clark, 1996; Johnson and Wilson, 2002; Kehoe et al., 2004; Mayr and Siddika, 2018; McCarthy et al., 2014). In most cases, the VOT changes occur to the minority language. Johnson and Wilson (2002) found that their English-Japanese bilingual children growing up in Canada produced voiceless stops with long lag values in English but they also did so in Japanese whereas they should have produced them in the short lag region. This result suggests <u>transfer of long lag voicing</u> from English into Japanese. Another pattern that has been reported is <u>delay in acquisition of lead voicing</u>. This pattern is not easy to separate out from developmental effects since lead voicing is acquired late in many languages. However, Mayr and Siddika (2018) documented a virtual absence of prevoicing in the productions of target voiced stops in Sylheti in third-generation English-Sylheti children and reduced presence of them (i.e., approximately 18%) in second-generation children, suggesting that bilingualism played a role. Linguistic experience was also implicated given the different results between second- and third-generation bilingual children: the second-generation children were growing up in households where Sylheti was spoken whereas the third-generation children mainly heard English in their homes.

Some studies have reported VOT changes to the majority language as well. One type of pattern is <u>delay</u>. For example, Kehoe et al. (2004) found that two out of four German-Spanish bilingual children growing up in Hamburg Germany, aged 2;0 to 3;0, produced German voiceless stops in the short-lag region, whereas the monolingual controls produced them in the long-lag region at this age. Fabiano-Smith and Bunta (2012) also documented VOT values in the short lag region for English /p/ and /k/ for their bilingual Spanish-English three-year-olds growing up in the United States, whereas monolingual English-speaking children produce target voiceless stops in the short lag region only at the early stages of development.

Finally, some studies have not documented any patterns of cross-linguistic interaction. Deuchar and Clark's (1996) study of a Spanish-English child indicated similar findings to those of monolinguals. Their subject, Manuela, produced voiced stops as short lag and voiceless stops as long lag in English, and made a contrast in the short lag region for Spanish, which is also typical of Spanish monolingual children. Khattab's (2000) study of VOT acquisition in slightly older Arabic-English children (ages 5, 7, and 10 years) also revealed few differences that could be directly related to bilingualism. The bilingual children produced VOT values for short and long lag stops in English that were similar to those of monolinguals.

1.3.2. Majority language: lead vs. short lag

We are aware of only one study which has examined VOT in bilingual children when the majority language contained a lead – short lag distinction. Stoehr et al. (2018) studied the acquisition of VOT in bilingual German-Dutch children growing up in the Netherlands. Dutch contains a lead – short lag whereas German, a long lag – short lag distinction. Stoehr et al. (2018) found few differences in the acquisition of VOT in the majority language, Dutch. The monolingual and bilingual children produced voiceless stops with similar VOTs (i.e., in the short lag region), although the bilingual children still produced significantly fewer stops with lead voicing than the monolingual children (30% vs. 50%). Stoehr et al. (2018) found greater differences in the acquisition of VOT in the minority language, German. The bilinguals produced voiceless plosives with shorter VOTs than monolingual German children. They also produced a higher percentage of stops with lead voicing in German than the monolinguals. Stoehr et al.'s (2018) findings are of interest to us since we focus on acquisition of VOT in the majority language, French, which is characterized by a lead – short lag distinction.

1.4. Models of cross-linguistic interaction and research predictions

In formulating predictions, we consider two models of cross-linguistic interaction: Paradis and Genesee's (1996) framework of cross-linguistic interaction and the Speech Learning Model (SLM) of Flege (1995). According to Paradis and Genesee (1996), three types of interaction can be expected: acceleration (a certain property emerges earlier in a bilingual than would be the norm in a monolingual), delay (a certain property emerges later in a bilingual than would be the norm in a monolingual), and transfer (the incorporation of a grammatical property into one language from the other). Delay and transfer have been reported in bilingual VOT development whereas acceleration has not been reported.[1] As mentioned above, children may be delayed in their acquisition of long lag voicing (Fabiano-Smith and Bunta, 2012; Kehoe et al., 2004); they may also be delayed in the acquisition of lead voicing (Mayr and Siddika, 2018; Stoehr et al., 2018). Patterns consistent with transfer of long lag and lead voicing have also been documented (Kehoe et al., 2004; Mayr and Siddika, 2018).

The SLM although typically employed to explain phonetic development in second language acquisition may also be useful for capturing patterns of cross-linguistic interaction in young bilinguals. The acquisition of a similar (but not identical) L2 sound may result in equivalence classification which prevents a new L2 category from being formed and the categories of the L1 and L2 are merged. Transfer of long lag voicing into a language with target short lag stops or delay in long lag voicing may lead to similar VOT values in the two languages and thus result in a merger of categories. It is also possible that children distinguish their two languages in terms of VOT values but their categories are different from those of monolinguals. The acquisition of a similar L2 sound may lead to an opposite phenomenon in which the two categories move away from each other to avoid crowding the phonetic space. These ''deflecting'' phenomena have also been reported in the acquisition of VOT. Mack (1990) reported excessively high VOT values for English long lag stops (e.g., 108 ms) in a 10-year-old French-English bilingual child. Since the child produced French voiceless stops also in the long lag region (e.g., 66 ms), the long VOTs in English allowed the child to maintain a phonetic contrast between his L1 and L2 systems.

In this study, the bilinguals have differing L1s (i.e., the home language which is other than French). We divide them into those speaking lead – short lag (e.g., Spanish, Italian, Portuguese) and long lag – short lag (e.g., English, German) VOT languages. We refer to these two groups as Bi – Lead and Bi – Long respectively. Since French is also characterized by a lead – short lag contrast, we predict no difference between the monolingual children and Bi – Lead children. We predict differences, however, between the monolinguals and the Bi – Long children. In the case of target voiceless stops in French, Bi – Long children may produce them with longer VOTs than monolinguals due to transfer of long lag voicing from their L1. This would then be an example of an assimilation or merger effect since it would lead to similar VOT values in the two languages. In the case of target voiced stops, bilinguals may produce fewer instances of lead voicing than monolingual children due to the influence of their other language which does not contain lead voicing. We refer to this pattern as delay; however, it also results in a merger since target voiced stops in both languages would be characterized by similar (low) numbers of productions with lead voicing. A summary of the research predictions for VOT in French is given in Table 1.

Stoehr et al. (2018) did not observe any differences between the VOTs of monolinguals and bilinguals in their productions of target short lag stops when the majority language was a lead – short lag language. She documented differences in the productions of target lead voicing, however: the bilinguals produced less lead voicing. Thus, an alternate finding could be that there is no cross-linguistic interaction at least in the case of target voiceless stops.

[1] Stoehr et al. (2018) observed more lead voicing in the production of German voiced stops by her German-Dutch bilingual than German monolinguals, which she interpreted as a possible manifestation of acceleration since adult German speakers produce lead voicing to a certain extent.

Table 1
A summary of predictions of cross-linguistic interaction on French VOT values.

Bilingual's L1	Example of languages	Target voiceless stops	Target voiced stops
Lead – short lag	Spanish, Italian, Portuguese	No effect	No effect
Short – long lag	English, German	Longer VOTs	Less lead voicing

Apart from the focus on cross-linguistic interaction, our data aim to contribute to findings on VOT in French, which is understudied in children. Apart from Allen's (1985) study on six children, aged 1;9 to 2;8, and Splendido's (2014) study of six French-speaking bilingual and two monolingual children acquiring French and Swedish in Sweden, there are few studies of VOT on children acquiring European French. We examine whether there are developmental effects on VOT between younger and older children and between children and adults. We also examine whether we observe the influence of place of articulation (PoA) (dorsal consonants have longer VOTs than coronals which in turn have longer VOTs than labials) and vowel type (stop consonants preceding high vowels have longer VOTs than those preceding round and low vowels) on VOT values, as has been reported for French-speaking adults (Nearey and Robert, 1994) and children (Splendido, 2014).

2. Method

2.1. Participants

The participants were selected from a larger study (Kehoe and Girardier, 2020) in which 101 French-speaking children aged 3 to 6 years (2;11–6;10) were tested in Geneva Switzerland. The VOT data are based on a subset of children from this study (n = 42). We selected all Bi – Long (n = 13) and then selected monolingual (n = 16) and Bi – Lead (n = 13) so that all of the groups had the same average age (Bi – Long: Mean = 56.37 months; sd. = 15.07 months; Bi – Lead: Mean = 56.38 months; sd. = 14.78; Monolinguals: Mean = 56.19, sd. = 15.35). More monolinguals than bilinguals were selected in order to achieve age equivalence amongst groups. A one-way Analysis of Variance (ANOVA) indicated that there were no significant age differences between the three groups ($F(2, 39) = .04$, $p = .96$). In addition, we tested 15 adults (aged 18 to 27 years). All adults were university students. They were monolingual speakers of French who had grown up in French-speaking Switzerland. Some of them also spoke English and German as second language learners, but they all indicated that they were not proficient speakers of these languages.

Bilingual status for the children was based on a parent questionnaire in which parents indicated whether their child spoke another language at least 30% of the time in addition to French. They were required to indicate which language the child spoke at home and with whom, and at what age the child had acquired French. They had all acquired French before the age of three years except for one child who started learning French at 3;4.[2]

Parents were also required to judge the language usage of French and the other language on a scale from 1 to 5 (1: only speaks other language; 2: speaks other language more than French; 3: speaks other language the same amount as French; 4: speaks French more than the other language; 5: only speaks French). Because of the small number of children who were dominant in the home language, we formed two dominance groupings: those who were dominant in French (scale 4) and those who were not (scale 2–3). There were more children dominant than not dominant in French (Bi – Lead: Dom = 8; Not dom = 5; Bi – Long lag: Dom = 8, Not Dom = 4). There was missing data on one child.

Information on the monolingual and bilingual participants including age, gender, languages spoken, age of acquisition of French, and dominance in French is presented in Tables A.1 and A.2 in Appendix A. As Table A.2 indicates, the languages spoken by the long lag group included English, German, Norwegian and Swedish and the languages spoken by the lead group were Catalan, Italian, Portuguese, Spanish, and Romanian. In the long lag group, four children were trilinguals speaking two different languages at home. In three cases, the two home languages had different VOT typology. We included these three children, nevertheless, because the language spoken by the mother was a long-lag VOT language. Studies point to the primacy of maternal versus non-maternal input in influencing language development (Hoff, 2003; Hurtado et al., 2008; Stoehr et al., 2019). Finally, a methodological limitation was that we did not collect individual measures of socioeconomic status (SES) for each child; however children attended kindergartens and schools in middle-class areas of Geneva.

[2] There was no evidence that this child patterned differently from the other bilingual children.

Table 2
Stimuli for the VOT test.

Stop consonant	Vowels		
	i	o	a
p	*piscine* "pool"	*pomme* "apple"	*papillon* "butterfly"
t	*tigre* "tiger"	*tortue* "turtle"	*table* "table"
k	*kiwi* "kiwi fruit"	*cochon* "pig"	*cadeau* "present"
b	*biberon* "baby bottle"	*botte* "boot"	*bateau* "boat"
d	*dinosaure* "dinosaur"	*dauphin* "dolphin"	*dame* "lady"
g	*guitare* "guitar"	*gomme* "eraser"	*gâteau* "cake"

2.2. Stimuli

Following Splendido (2014), we used a picture naming task disguised as a memory game to elicit words containing word-initial stop consonants. Stop consonants were elicited in three vowel contexts /i, o, a/.[3] Table 2 provides a list of the target words. Most words were present in the Developpement du langage de production en français (DLPF) version 3 (31–36 mois) (Bassano et al., 2005). The remaining words (*dauphin* "dolphin", *gomme* "eraser", & *dinosaure* "dinosaur") were considered to be familiar to children as young as 3;0. In addition, some words starting with stop consonants were elicited as part of a denomination task for another study (e.g., *panier* "basket", *casque* "helmet", *carafe* "carafe", *garage* "garage"; Kehoe and Girardier, 2020). These words were included if they were produced by multiple children. Most of the words were bisyllabic but we also included some monosyllabic and trisyllabic words. Given that syllable number may potentially influence VOT, which is a temporal measure, our statistical analyses also included syllable number as a control variable.

2.3. Procedure

Children were tested individually in a quiet room at the crèche or public school. They were tested in the presence of two French-speaking graduate students. One student interacted with the child while the other student managed the recording equipment. Before the "memory game" started, the child was asked to name each picture. Following this, the experimenter and child played memory with the explicit aim of obtaining multiple productions of the stimulus words. An adaptation was made in the case of young children. When two cards were turned over, they remained visible to the child for the rest of the game to facilitate the task. Children's productions were recorded with a portable digital tape-recorder (Marantz Tascam DR-2d) and unidirectional condenser microphone placed on a table in front of the child.

Adults were tested in a quiet room on the university campus. They played the same memory game that the children played. They were requested to say the words as they normally would when playing a memory game. The adult productions were recorded with the same recording equipment as the children.

In total, children produced 2241 words that contained stop consonants. Fourteen percent of tokens (n = 314) could not be analyzed because there was: no recognizable burst (n = 154), noise overlay (n = 60), a phonological error such as a place or manner of articulation substitution (n = 72; e.g., *botte* "boot" produced as [vɜt]; *cochon* "pig" produced as [toʃɔ̃]) or because they were whispered (n = 26). On average, each child produced 26 words containing target voiceless stops and 20 words containing target voiced stops. Adults produced 1064 words of which 4% could not be analyzed (n = 45 due to no recognizable burst or noise overlay). They produced on average 36 words containing target voiceless and 31 words containing target voiced stops.

[3] Vowel type /o/ included words with [ɔ] (e.g., *gomme* "eraser") or [o] (e.g., *dauphin* "dolphin").

2.4. Data transcription and analyses

Using Phon, a software program specifically designed for the analysis of phonological data (Rose and MacWhinney, 2014), each child's wave file was segmented, and stimulus words were identified and transcribed. Two French-speaking graduate students, who had experience in phonetic transcription, including training in the speech laboratory, performed the segmentation and transcription. Words starting with a stop consonant were extracted for the analysis of VOT.

Acoustic analyses were conducted in Praat (Boersma and Weenink, 2016) by the second author. 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). In the case of multiple bursts, the first burst was measured. Following Davis (1995), two values were recorded for target voiced stops: 1. Lead

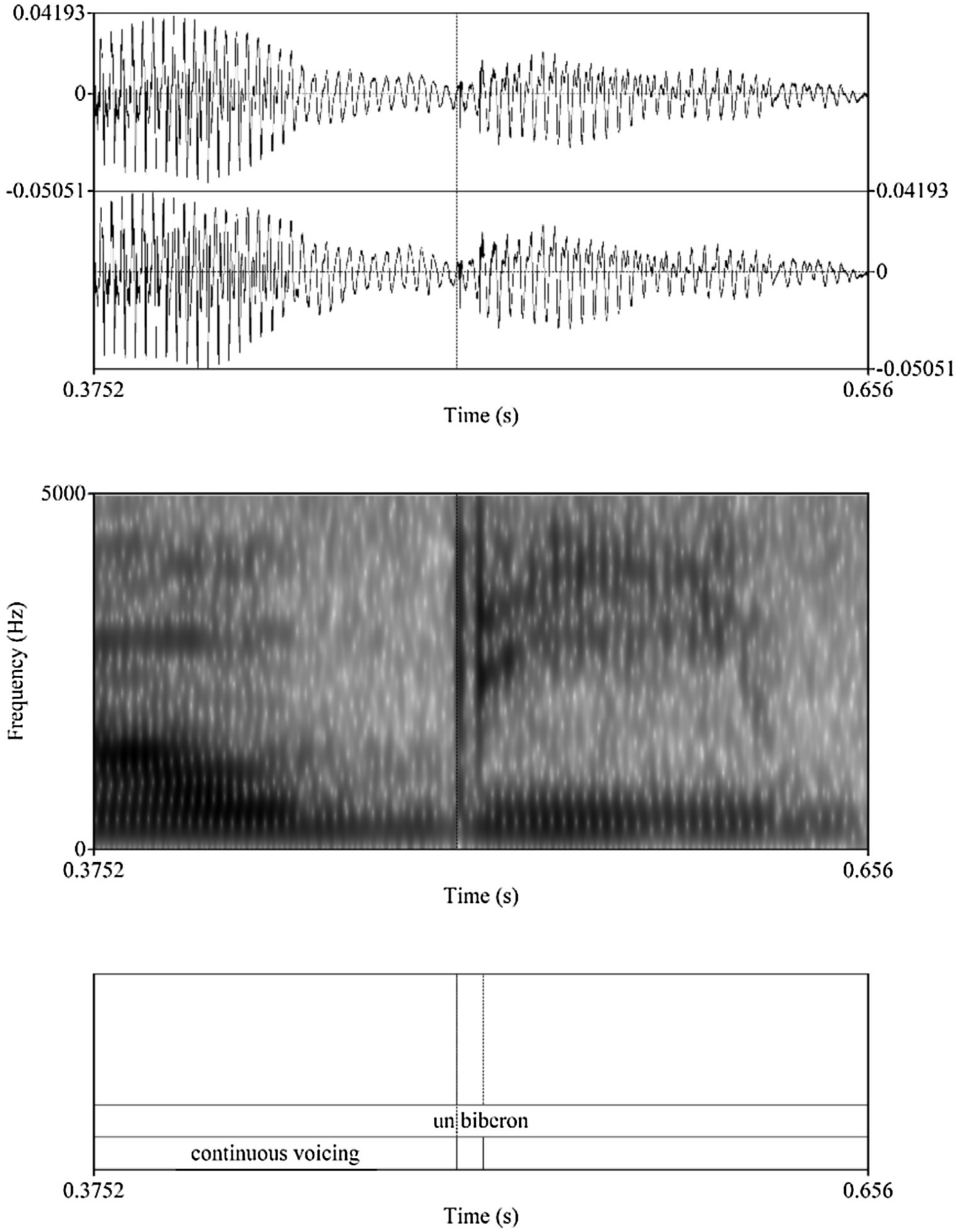

Fig. 1. Time waveform and spectrogram from Praat showing VOT measurement of the word *biberon* ‘‘baby bottle’’ in the presence of continuous voicing. Lead voicing could not be measured.

VOT (duration of voicing prior to burst); and 2. Lag VOT (period between release burst and first glottal pulse after the release). Like MacLeod (2016), we tested children in a natural setting and did not exclude the use of an article preceding the target word. This meant that a large percentage of productions (i.e., 44%) were preceded by continuous voicing preventing the measurement of lead voicing. Following MacLeod (2016), we applied the rule that lead VOT needed to be preceded by a period of 20 ms without voicing in order to distinguish it from continuous voicing. We found that children's productions of voiced stops constituted three groups: 1. Productions with continuous voicing (i.e., presence of a determiner) in which case lead voicing was not measurable; 2. Productions without continuous voicing in which lead voicing was present; 3. Productions without continuous voicing in which lead voicing was not present. Figs. 1–3 displays examples of these three types of productions of target voiced stops.

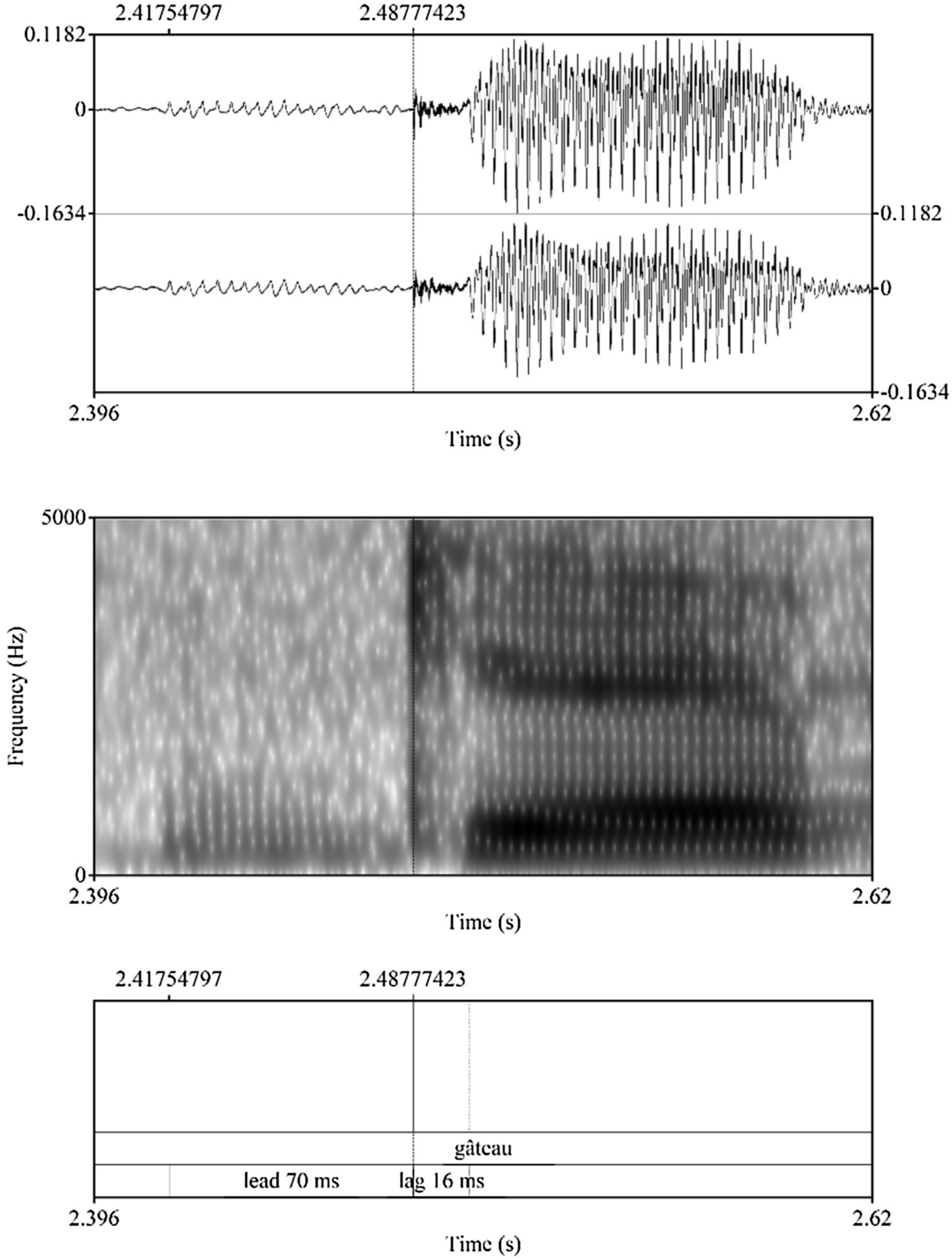

Fig. 2. Time waveform and spectrogram from Praat showing VOT measurement of the word *gâteau* ''cake'' indicating the presence of lead voicing and a short lag period after the burst.

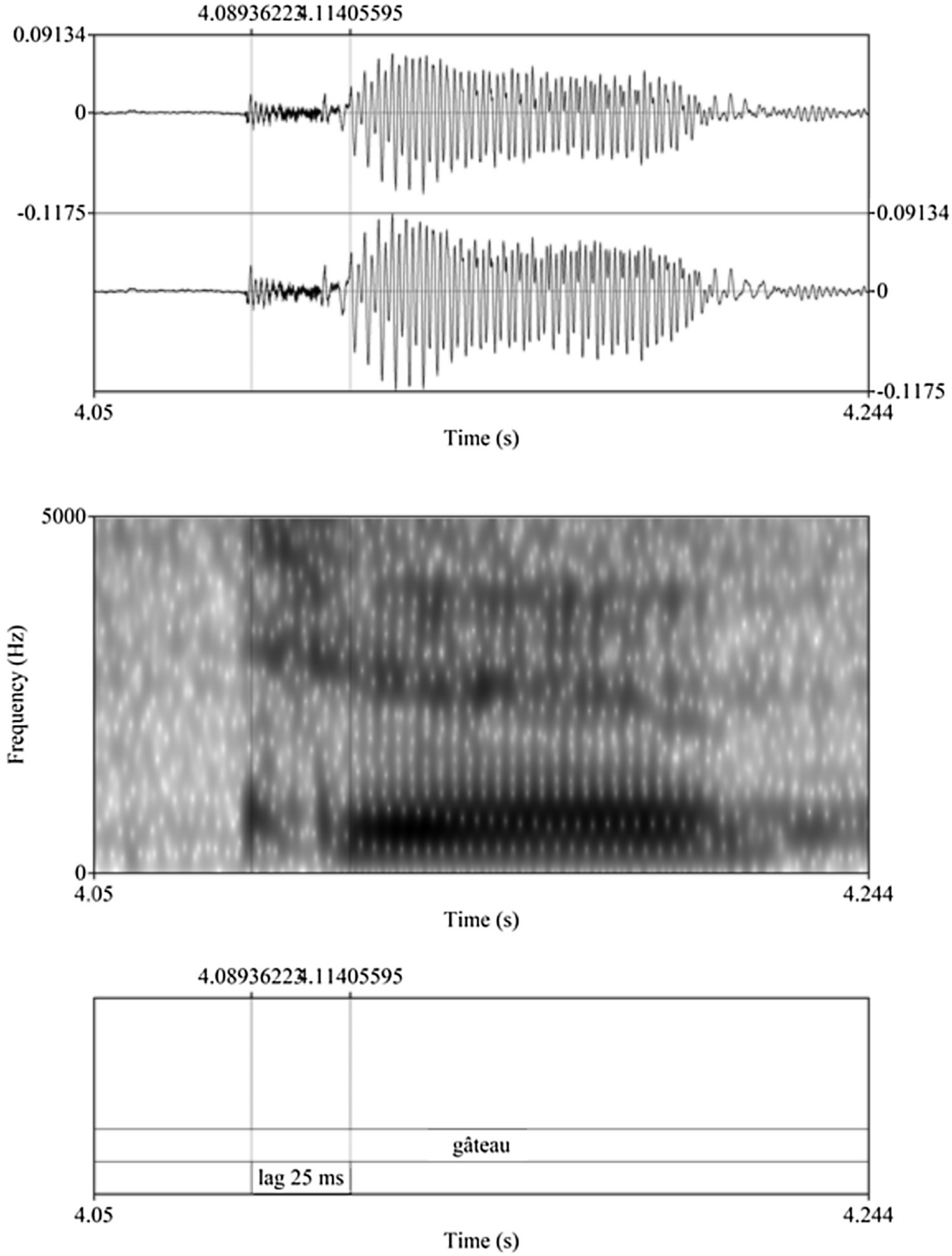

Fig. 3. Time waveform and spectrogram from Praat showing VOT measurement of the word *gâteau* ‘‘cake’’ in which no lead voicing is present.

2.5. Reliability

A subsample of words (n = 200 from 4 different children) was reanalyzed by a second researcher (first author) applying the same procedure as described above. The mean VOT values for the original analysis were 28.78 ms and for the second analysis, 28.87 ms. The correlation coefficient between the two sets of scores was .98 suggesting good inter-tester reliability.

2.6. Statistical analyses

In the statistical analyses, we examined the children separately and then grouped them with the adults to obtain information on whether children differed from adults in their realization of VOT. We conducted linear mixed models to

Table 3
Summary of positive VOT values across age group and sounds.

Age group	Stop	*n*	Mean VOT	sd.	VOT range
3 to 4	/p/	185	19.58	15.27	1.85–78.83
	/t/	167	30.16	28.12	5.5–181.14
	/k/	205	47.14	32.64	8.18–182.06
	/b/	145	9.97	9.35	0–69.59
	/d/	121	14.15	11.03	1.5–84.41
	/g/	169	22.13	17.79	0–103.27
5 to 6	/p/	187	25.15	20.61	3.6–143.38
	/t/	147	42.83	33.96	5.2–200.67
	/k/	197	50.20	28.42	10.23–136.61
	/b/	137	10.05	9.13	0–58.49
	/d/	112	13.07	9.64	0–57.95
	/g/	155	22.12	15.68	0–76.62
Adults	/p/	177	25.36	12.91	6.79–80.22
	/t/	189	43.85	28.74	11.71–147.17
	/k/	181	54.44	25.79	19.82–132.89
	/b/	159	8.45	6.92	0–54.64
	/d/	159	12.51	9.53	0–82.25
	/g/	153	14.39	9.71	0–63.10

examine the effect of predictor and control variables on positive VOT values and mixed effect logistic regression to examine the effect of predictor and control variables on the presence or absence of lead voicing. The analyses were performed using R statistical software (R Development Core Team, 2015) and the lme4 package (Bates et al., 2015) for mixed models. To evaluate the contribution of predictor and control variables, we performed pairwise model comparisons between a saturated and a more restricted model. The saturated model included all main effects whereas the restricted model omitted the predictor under consideration. Comparisons were made using log likelihood ratio tests which yielded a chi-squared statistic.

In the analyses of the children data, the main predictor variable was bilingual status (Mon, Bi – Lead, Bi – Long). We included, in addition, control variables: age (in months), voice (target voiced vs voiceless), PoA (labial, coronal or dorsal), vowel type (a, i, o), syllable number (1, 2, 3 syllables), and the interaction age*voice since children may realize the voicing distinction differently across age range. The dependent variable was the positive VOT value obtained for both target voiced and voiceless stops. In the combined child and adult data, we examined the influence of age on positive VOT values while including control variables. In this analysis, children were divided into two age groups: 3 to 4 years (2;11 to 4;11) and 5 to 6 years (5;1 to 6;7). These groupings were also used in the presentation of the descriptive statistics. Finally, we examined whether being dominant in French influenced the VOT findings by comparing monolinguals to Bi – Long children who were dominant or not dominant in French. In all analyses, random factors included intercepts for participant and item. Random slopes on fixed effects were initially included but subsequently removed due to lack of convergence.

3. Results

3.1. Analyses on positive VOT values

Table 3 provides descriptive information on VOTs for the six stop consonants produced by children, aged 3 to 4 years, 5 to 6 years and by adults. It shows the mean (positive) VOT value for target voiced and voiceless stop consonants. Mean VOT values were 20–25 ms for /p/, 30–44 ms for /t/, 47–54 ms for /k/, 8–10 ms for /b/, 13–14 ms for /d/ and 14–22 ms for /g/.

First, we analyzed whether bilingual status influenced the realization of positive VOT values by the French-speaking children. The results of a linear mixed model indicated that bilingual status did not improve model fit to data ($\chi^2(2) = 1.81$, $p = .41$).[4] Monolinguals and both groups of bilinguals produced target voiceless stops with mean values of approximately 35 ms (Bi – Lead: 35 ms; Bi – Long lag: 39 ms; Mon: 34 ms) and target voiced stops with mean values of approximately

[4] We examined whether recoding the data so that the predictor variable had two levels: lead (monolinguals and Bi – Lead) vs. long lag (Bi – Long lag) improved model fit to data. This was not found to be the case ($\chi^2(2) = 1.75$, $p = .19$).

Table 4
Mean positive VOT values according to bilingual status and voicing category in the children's data.

	Bi-Lead			Bi-Long			Mon		
	Mean	sd.	*n*	Mean	sd.	*n*	Mean	sd.	*n*
Voiceless	34.77	30.49	318	38.96	30.63	366	34.39	27.58	404
Voiced	15.35	14.38	275	16.80	13.24	249	15.12	14.15	315

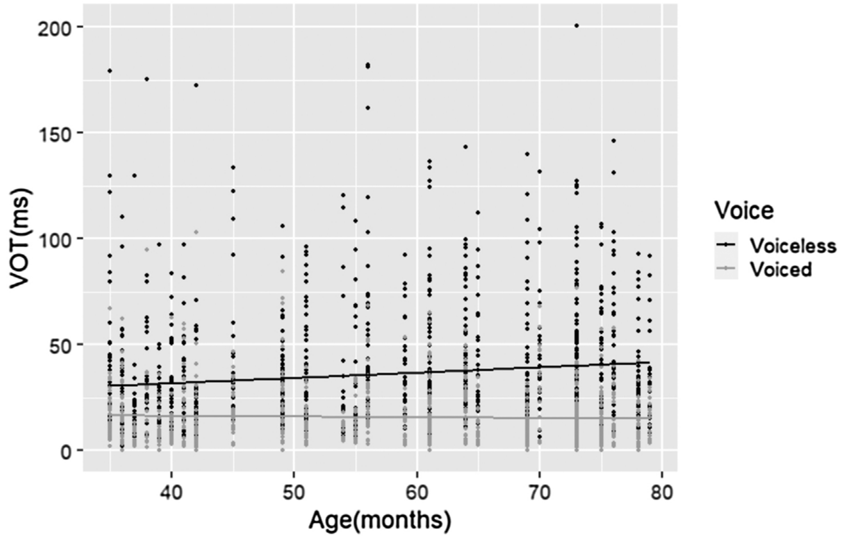

Fig. 4. Positive VOT values for target voiced and voiceless stops as a function of age (in months). Monolingual and bilingual children are combined.

15 ms (Bi – Lead: 15 ms; Bi – Long lag: 17 ms; Mon: 15 ms) (see Table 4). They demonstrated a great deal of variability and realized many stops with VOTs in the long lag region; however, these tendencies were evident across all groups. Although bilingual status was not significant, control variables, PoA ($\chi^2(2) = 14.23$, $p < .001$), vowel type ($\chi^2(2) = 11.48$, $p = .003$) and the interaction between voice and age ($\chi^2(1) = 19.87$, $p < .001$) were significant. As Fig. 4 shows, positive VOTs for target voiceless stops increased with age but not those for target voiced stops. The influence of word length (i.e., syllable number) on VOT was not significant ($\chi^2(1) = 1.32$, $p = .25$). We performed Tukey multiple comparisons using the emmeans function in R (Lenth et al., 2018) in order to determine whether the voicing contrast, PoA and vowel types were significantly different from each other. Results indicated that children produced longer VOTs for voiceless in contrast to voiced stops ($t = 5.57$, $p < .001$), longer VOTs for dorsal relative to labial consonants ($t = 3.78$, $p = .002$), and longer VOTs before high vowel /i/ than before low vowel /a/ ($t = 3.40$, $p = .006$). All other comparisons were not significantly different. Table A.1 in Supplementary Materials A presents means and standard deviations for target voiced and voiceless stops according to vowel type. As can be observed, VOTs for /t/ and /k/ before /i/ were very long (67–76 ms). Figs. B.1 and B.2 in Supplementary Materials B illustrate the influence of PoA and vowel type in the monolingual and bilingual groups. These graphs show that the influence of PoA and vowel type was similar across monolingual and bilingual groups.

In a second analysis, we ran linear mixed models including the variable age (3 to 4, 5 to 6, adult) and control variables on a combined database which included child and adult participants. We also included the interaction between age and voice since developmental effects may differentially affect the VOT of target voiced versus voiceless stops as observed in the child data. We did not include bilingual status as variable since previous analyses showed that it had no influence on the child data. Results indicated a significant interaction between age and voice ($\chi^2(2) = 53.51$, $p < .001$). Tukey multiple comparisons indicated that all age groups realized a significant voicing distinction on the basis of positive VOT values (3 to 4: $t = 4.56$, $p = .001$; 5 to 6: $t = 6.04$, $p < .001$; Adult: $t = 7.35$, $p < .001$). In addition, adults produced voiceless stops with significantly longer VOTs than children aged 3 to 4 ($t = 3.10$, $p = .03$). There were no other significant age differences. Control variables, PoA ($\chi^2(2) = 11.50$, $p = .003$) and vowel type ($\chi^2(2) = 9.00$, $p = .007$) were significant. The influence of age-group on VOT (organized according to stop consonant) is shown in Fig. 5.

Finally, we compared monolinguals to children in the Bi – Long group who were dominant or not dominant in French. Caution should be exerted in the interpretation of these findings since eight Bi – Long children were dominant and only four

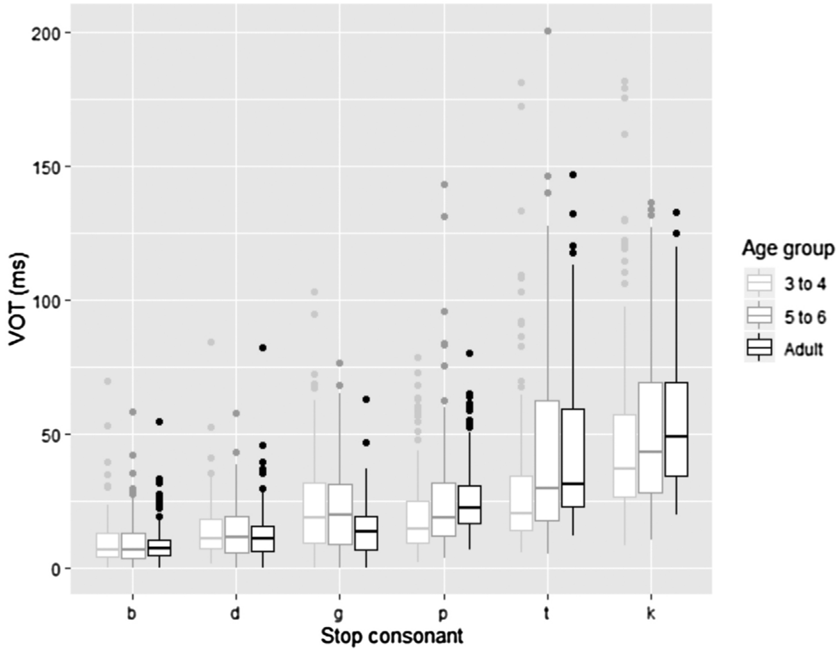

Fig. 5. Box plot display of positive VOT values for target voiced (b, d, g) and voiceless stops (p, t, k) in age range: 3 to 4, 5 to 6, and adults.

Table 5
Means and standard deviations of positive VOT values for monolinguals and Bi – Long children who were dominant and not dominant in French.

	Monolingual			Dominant			Not dominant		
	Mean	sd.	*n*	Mean	sd.	*n*	Mean	sd.	*N*
Voiceless	34.39	27.58	404	36.70	30.45	221	44.40	29.78	122
Voiced	15.12	14.15	315	14.80	12.06	159	23.04	14.76	73

were not dominant in French. One child was excluded due to missing data. Table 5 presents the mean positive VOTs for target voiced and voiceless stops for monolinguals and the two groups of Bi – Long children. The VOTs for both target voiceless and voiced stops were greater when produced by children who were not dominant relative to children dominant in French or monolinguals, consistent with a possible influence of the L1 on VOT values in French. A linear mixed model which included control variables age, POA, vowel type and voice indicated that the main effect of dominance (Not Dominant, Dominant, Monolingual) was significant ($\chi^2(2) = 7.01$, $p = .01$). Pairwise comparisons revealed that children who were not dominant in French produced longer VOTs than monolinguals ($t = 2.60$, $p = .04$). Importantly, the same analysis comparing monolinguals to children in the Bi – Lead group who were dominant or not dominant in French yielded no significant effect ($\chi^2(2) = 1.58$, $p = .45$).[5]

In sum, we found no influence of bilingualism on positive VOT values in the main analysis. Bilingual children who grew up speaking a long-lag language in addition to French did not produce VOT values differently from monolingual children and from bilingual children who grew up speaking lead languages. When we separated the Bi – Long group according to language dominance, we found that children who had less exposure to French differed from monolinguals, suggesting some influence of bilingualism on VOT values. In addition, we found an interaction between age and the voicing contrast. In both databases (child and child + adult combined), VOT values for target voiceless stops increased with age. Finally, we found significant effects of control variables (PoA & vowel type) on VOT.

[5] We also examined whether the variable, age of acquisition of French, accounted for the VOT findings. Indeed, it emerged as significant in an analysis which included the BI – Long lag and the monolinguals ($\chi^2(1) = 6.88$, $p = .009$). This is not surprising since children who were non-dominant in French had later ages of acquisition of French (see Table A.2 in Appendix A). Crucially, age of acquisition did not emerge as significant in an analysis which included the BI – Lead and the monolinguals ($\chi^2(1) = .06$, $p = .80$).

Table 6
Percentages of productions with lead voicing by age in monolingual and bilingual children.

Age group	Mon		Bi-Lead		Bi-Long	
	Total[a]	%Lead	Total	%Lead	Total	%Lead
Age 3 to 4	104	15.38%	77	11.69%	49	2.04%
Age 5 to 6	78	41.03%	72	22.22%	90	13.33%
Adults	438	91.56%				

[a] Total is the total number of target voiced stops without continuous voicing.

3.2. Analyses on negative VOT values

3.2.1. Presence of articles

In order to determine whether children produced determiners more often with target voiced stops as a strategy to facilitate the realization of voiced stops, we counted the number of times determiners were realized with words containing target voiced versus voiceless stops. For the purposes of this analysis, any word spoken by the child directly preceding the target word (e.g., *un, une, le, la, les, du, des*, etc.) was counted as a determiner. Children realized determiners 72% of the time with target voiceless stops (788/1088) and 76% of the time with target voiced stops (639/839). A chi-square analysis indicated that this difference was not significant, although there was a tendency for greater numbers of determiners preceding target voiced than voiceless stops ($\chi^2(1) = 3.44$, $p = .06$). The production of a determiner preceding a target voiced stop resulted in continuous voicing 59% (380/639) of the time.[6]

3.2.2. A focus on lead voicing

To examine the influence of bilingualism on lead voicing, we reduced the data base to those productions of target voiced stops which were not realized with continuing voicing. This meant reducing the database of target voiced stops by 44% (369 of 839 target words were characterized by continuous voicing). Table 6 shows the percentages of tokens produced with lead voicing in the monolingual and bilingual children across age group as well as in the adult monolingual group. In the 3 to 4 group, only a small percentage of productions (2 to 15%) were realized with lead voicing; in the 5 to 6 group, a larger percentage of productions (13 to 41%) were realized with lead voicing. Adults produced lead voicing most of the time (91%).[7] Monolingual children produced the greatest number of productions with lead voicing; the Bi – Long group, the least.

We used binomial logistic regression to examine whether bilingualism influenced the realization of lead voicing. We entered the predictor variable, bilingual status, and control variables. We simplified the model by removing the random factor Item (which accounted for very little variance) due to a risk of over-parameterization. The analysis indicated that two factors significantly improved model fit to data: age ($\chi^2(1) = 5.08$, $p = .02$) and PoA ($\chi^2(2) = 10.89$, $p = .004$). Older children produced more lead voicing than younger children and the presence of lead voicing differed according to PoA. In addition, bilingual status was marginally significant ($\chi^2(2) = 5.29$, $p = .07$). Tukey multiple comparisons indicated that lead voicing was more frequent for labials than dorsals ($z = 3.20$, $p = .004$) and that bilingual children who belonged to the long lag group had marginally less lead voicing than monolinguals ($z = 2.31$, $p = .05$).

In sum, our analyses on productions of target voiced stops, which were not preceded by continuous voicing, indicated that lead voicing was not consistently produced even in the age range 5 to 6 years. There was a trend for lead voicing to be realized more often by monolinguals than by children in the Bi – Long group, although this result was only marginally significant. Age and PoA also influenced the realization of lead voicing.

4. Discussion

This study examined VOT in French-speaking monolingual and bilingual children, aged 3 to 6 years. The bilingual children spoke languages with a long lag-short lag distinction (e.g., English & German) and a lead-short lag distinction (e.g., Spanish & Italian). We predicted differences between monolinguals and bilinguals speaking a long lag language but no differences between those speaking a lead language, given that children in the latter group have the same voicing

[6] The use of a determiner did not always result in continuous voicing. There was sometimes a brief pause before the production of the target word.

[7] Adults did not frequently produce an article before the target word in the Memory game. We removed 34 tokens due to continuous voicing.

distinction as French. Apart from examining the influence of bilingualism, we examined the influence of age, PoA and vowel type on VOT. The overall results revealed minor effects of bilingualism and major effects of age, PoA, and vowel type on VOT production.

4.1. Cross-linguistic interaction in VOT

Many studies have shown that exposure to two languages influences children's development of VOT (Fabiano-Smith and Bunta, 2012; Johnson and Wilson, 2002; Kehoe et al., 2004; Khattab, 2000; Stoehr et al., 2018). The bulk of the research has focused on bilingual VOT acquisition when the majority language has a long lag – short lag distinction. In contrast, this study examined the influence of bilingualism on VOT acquisition when the majority language has a lead – short lag distinction. The only other study which has investigated such a situation is Stoehr et al. (2018), which examined acquisition of VOT in bilingual Dutch-German children growing up in the Netherlands. They found few effects of bilingualism on Dutch, the majority language, except for reduced presence of lead voicing. Similarly, we found few effects of bilingualism on French, the majority language, except for a tendency toward reduced lead voicing in bilingual children who spoke a language with a long lag – short lag contrast.

We had hypothesized that children belonging to the Bi – Long group might produce target voiceless stops with longer VOTs than monolinguals due to the influence of their L1. Similar effects have been reported for bilingual children acquiring Japanese in Canada (Johnson and Wilson, 2002) or acquiring Spanish in Germany (Kehoe et al., 2004). In our study, bilingual children were acquiring French in French-speaking Switzerland, and, in most cases, French was their dominant language. We found no differences between the VOT values of monolinguals and both groups of bilinguals. Average VOTs and standard deviations were of similar magnitude across all three groups (see Table 4). The only hint that bilingualism influenced positive VOT values was when we separated out the Bi – Long group according to language dominance. Here, we observed that children not dominant in French had higher VOT values than monolinguals. Thus, speaking a long lag language was not sufficient to change VOT values relative to monolinguals; rather speaking a long lag language at least half of the time was necessary to influence VOT values. The absence of strong effects of bilingualism on positive VOT values in French is consistent with Stoehr et al.'s (2018) general finding that cross-linguistic interaction in VOT acquisition was not strongly evident in the majority language Dutch. Our results differ from their findings, nevertheless, in documenting some influence of language exposure/dominance on positive VOT values in the majority language. Our analysis should be interpreted with caution, however, due to the small numbers of children who were not dominant in French.

We had predicted less lead voicing in the Bi – Long group due to the influence of the L1, a prediction which was tentatively supported in the current study. As indicated by Table 6, children in the Bi – Long group produced fewer tokens with lead voicing than monolinguals and children in the Bi – Lead group. The reduced numbers of tokens analyzed (due to the presence of continuous voicing) compromised statistical power, possibly preventing a statistically significant result to emerge.[8] We also observed a tendency for children in the Bi – Lead group to realize fewer tokens with lead voicing than the monolinguals, a finding which may hint at bilingualism leading to a delay in the acquisition of lead voicing; however, this finding would need to be confirmed in a larger group of children. Overall, our findings are consistent with Stoehr et al.'s (2018) study which found that the main effect of bilingualism on VOT in the majority language, Dutch, was the reduced presence of lead voicing. In their study, the children produced similar percentages of tokens with lead voicing in their German and Dutch leading to a lack of language differentiation (i.e., one voiced category) for target voiced stops. Our group of bilinguals may have had only one voiced category for French and their L1 but we are unable to confirm this, given that we only measured VOT in French.

Stoehr et al. (2019) found that bilingual children's VOT patterns correlated with their parents. They were influenced by their mothers' non-native speech in the majority language. Thus, it cannot be excluded that what is being interpreted here as cross-linguistic interaction reflects instead the influence of parental input on VOT: the Bi – Long children may have been exposed to non-native French which contained higher than average positive VOTs and fewer productions with lead voicing.

4.2. VOT in French

A secondary aim of the study was to contribute to findings on VOT in French. We found that the young adult participants produced relatively long VOTs for target voiceless stops (/p/: 25 ms; /t/: 44 ms, /k/:54 ms). In VOT research, it has often

[8] One other factor that might have compromised the lead voicing findings is that two children in the Bi – Long lag group spoke either Swedish or Norwegian as L1. There is some evidence that some varieties of Swedish and Norwegian have a contrast between prevoiced voiced stops and aspirated voiceless stops meaning that these children could have had target VOT values for voiced stops in their L1 similar to French (Helgason and Ringen, 2008).

been noted that two-category VOT languages choose two adjacent zones along the VOT dimension (e.g., lead-short lag; short lag-long lag but not lead-long lag); however, exceptions have been observed whereby speakers produce moderately long ''intermediate'' values of voicing lag rather than short lag values (Abramson and Whalen, 2017; Caramazza et al., 1973; Raphael et al., 1995). Such intermediate VOT values have been documented in bilingual (Flege and Port, 1981; Laeufer, 1996) but also in monolingual speakers (e.g., Kong et al., 2012; Raphael et al., 1995). In our study, the monolingual adult speakers produced average VOTs for /t/ and /k/ which entered this intermediate zone. A closer analysis of the data reveals that the intermediate lag values stem from the conditioning effect of PoA and vowel type on VOT: VOTs for /k/ were greater than 35 ms and VOTs for /t/ and /k/ before /i/ were greater than 60 ms (see Table C.1 in Supplementary Materials C).

Nearey and Rochet (1994) found that French adults produced prevoicing on 91% occasions with the average length of prevoicing being 96 ms. We also found that the French adults used prevoicing 91% of the time; however, the average length of prevoicing was 73 ms (sd = 33 ms) shorter than that reported by Nearey and Rochet (1994). Indeed on 25% of occasions, the length of prevoicing was very short (less than 50 ms), which may be one of the factors that contributed to the low percentage of lead voicing by the children (see below).

Turning to the child data, our analyses documented two developmental effects: target voiceless stops were produced with longer VOTs and target voiced stops were realized more often with lead voicing over time. The findings for voiceless stops are somewhat surprising since it might be assumed that, as children gain more articulatory and laryngeal control, their VOT values approximate the target ''short lag'' system. Instead, we observed that younger children started off producing short VOTs and gradually increased them such that their VOTs approximated the target ''intermediate'' system at least for /t/ and /k/. Splendido (2017) also observed an increase in VOT in her two monolingual French-speaking subjects tested longitudinally from 3;7/4;0 to 5;6/6;0. At the final session, the average VOT across voiceless stops was 77 ms and 52 ms for the two children respectively. She interpreted the long VOT values as reflecting overshooting consistent with reports of similar patterns by French-speaking children in the literature (Ryalls and Larouche, 1992). Our findings are not consistent with ''overshooting'' but with a gradual approximation toward the target system. Intermediate VOT values and high variability were characteristic of the adult system as well. Given that the youngest children produced the shortest VOTs, results are consistent with previous claims that short lag VOT is the unmarked VOT value and that development is characterized by acquisition of longer (long lag or intermediate) VOTs (Kehoe et al., 2004).

The second developmental effect was the increased realization of lead voicing over time. Our study documented low levels of lead voicing in the children, a finding which is at odds with MacLeod (2016) for French and Okalidou et al. (2010) for Greek, which documented greater realization of lead voicing in children of a similar age. We acknowledge that the high use of continuous voicing compromised the analysis of target voiced stops; however, such constraints were present in MacLeod's (2016) study and, nevertheless, greater use of lead voicing was observed. Apart from the fact that lead stops are articulatorily difficult and considered marked (Lowenstein and Nittrouer, 2008), other reasons for the low use of lead voicing may relate to the input. The children were growing up in Geneva, Switzerland, an international city characterized by many bilinguals. Even the input to the monolinguals may have consisted of non-native speech with reduced use of lead voicing. Furthermore, the prevoicing employed by the adult monolinguals was often very short, perhaps providing fewer perceptual cues of voicing to the children. Sometime after six years, the children presumably develop the articulatory and laryngeal control necessary to produce consistent lead voicing. We did not find strong evidence, as proposed by Allen (1985), that children display increased use of determiners with target voiced as opposed to voiceless stops to aid them with the ''prevoicing problem''. Nevertheless, as observed by MacLeod (2016), continuous voicing appears to be a tool that plays to the advantage of French-speaking children, allowing them to realize target voiced stops as voiced most of the time.

Our analyses on the child data indicated PoA effects. VOTs for dorsal stops were significantly longer than for labial stops. There were no differences between dorsal and coronal nor between coronal and labial stops, consistent with findings in the VOT literature that PoA effects are not always present between all places of articulation (Cho and Ladefoged, 1999; Lisker and Abramson, 1964; Nearey and Rochet, 1994). Our analyses on the child data also indicated effects of vowel type: VOTs were longer before /i/ than before /a/. Influence of vowel type has been reported frequently in the literature on adults (Nearey and Rochet, 1994; Serniclaes, 1987) but Splendido (2014, 2017) was one of the first to have documented this effect in monolingual and bilingual French-speaking children as young as three to four years. Our results are consistent with hers in showing strong effects of vowel type on VOT particularly for stops /t/ and /k/.

5. Conclusion

This study examined the development of VOT in French-speaking monolingual and bilingual children, aged 3 to 6 years, as well as in French-speaking adults. We found that bilingualism influenced VOT acquisition in the majority language to a small degree. Bilingual children acquiring a long lag language had greater VOT values than monolinguals when they were not dominant in French. They also displayed a tendency to produce fewer productions of target voiced stops with lead voicing than monolinguals. Our results suggest that cross-linguistic interaction in the phonetic domain when tested in the majority language is not an inevitable outcome of bilingual acquisition but can be observed when language dominance is taken into consideration.

Our findings also provided information on VOT in French. Although French is purported to have a lead – short lag distinction, our results showed that voiceless stops were often realized in an intermediate lag VOT range. The realization of stops in the intermediate range stemmed from the conditioning effect of PoA and vowel type: VOTs for /k/s, and for /t/ before high vowel /i/ were intermediate to long. These findings point to the language-specific way in which the French voicing contrast is realized acoustically. Our young monolingual and bilingual children appear to be acquiring the language-specific phonetics of the voicing contrast in French without difficulty.

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Declaration of Competing Interest

There was no conflict of interest.

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Appendix A

Table A.1
Information on the monolingual participants including gender and age.

Child ID	Gender	Age
Age 3 to 4		
RL	F	2;11
PN	M	3;0
MR	M	3;3
GH	M	3;4
VM	M	3;9
CN	M	4;1
MS	M	4;1
SL	M	4;3
MS	F	4;8
Age 5 to 6		
BM	F	5;1
MI	F	5;4
GN	F	5;10
BS	M	6;1
GM	F	6;3
PB	M	6;6
VE	M	6;6
Adult		
LM	M	18
MF	F	21

Table A.1 (*Continued*)

Child ID	Gender	Age
EC	F	22
HF	M	22
LF	M	22
MJ	M	22
LE	F	22
ND	M	22
LM	F	22
TA	M	22
FS	M	23
IM	F	23
RW	M	23
LP	F	23
OD	M	23
LB	F	27

Table A.2
Information on the bilingual participants including gender, age, languages spoken at home, age of onset (of French) and dominance rating.

Child ID	Gender	Age	L1/L1+	L1 spoken by	L2 learned at	Age of onset	Dominance
Age group: 3 to 4							
VOT contrast: Long lag vs. Short lag							
CI	M	2;11	English	mother	home	0	Dom
AL	M	3;1	English	father	home	0	Dom
WJ	M	3;2	German	mother/father	crèche	2;9	Not dom
BC	F	3;4	Norwegian	mother	home	0	Dom
OL	F	4;3	English	father	home	0	Dom
VC	F	4;6	English	mother	home	0	
DGY	F	4;11	German	mother	home	0	Dom
VOT contrast: Lead vs. Short lag							
CE	M	3;0	Italian	mother/father	crèche	2;6	Not dom
RE	M	3;5	Portuguese	mother	crèche	0	Dom
AL	M	3;5	Spanish	mother/father	crèche		Dom
PS	F	3;6	Romanian/Italian	mother/father	crèche	1;0	Dom
MA	F	3;6	Spanish	mother	home	0	Dom
BS	F	4;7	Italian	mother/father	crèche	0;5	Not dom
DL	F	4;8	Catalan	father	home	0	Dom
Age group: 5 to 6							
VOT contrast: Long lag vs. Short lag							
LC	M	5;1	German/Swedish	mother/father	crèche	2;0	Not dom
OPA	F	5;4	English	mother/father	crèche	2;4	Not dom
BFJ	F	6;1	Swedish/Farsi	mother/father	crèche	2;0	Not dom
BM	F	6;3	German	mother	home	0	Dom
JL	F	5;9	English/Bosnian	mother/father	home	0	Dom
FG	M	6;4	German/Spanish	mother/father	home	0	Dom
VOT contrast: Lead vs. Short lag							
LA	F	5;9	Spanish	grandparents	home	0	Dom
PK	M	5;1	Spanish	mother	home	0	Dom
DSK	M	5;5	Portuguese	mother/father	school	3;4	Not dom
FA	M	6;1	Italian	mother/father	home	0	Dom
RA	F	6;1	Spanish	mother/father	crèche	2;0	Not dom
HD	M	6;7	Spanish	mother/father	crèche	2;0	Not dom

Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.lingua.2020.102937.

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