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Andrej Stopar
University of Ljubljana
https://orcid.org/0000-0001-9455-1820

Voice Onset Time (VOT) in L1 Slovenian Voiceless Stops and Its Transfer to L2 English

1. Introduction and literature review

In 1964, Lisker and Abramson introduced the concept of Voice Onset Time (VOT) as a measure to quantify the acoustic differences among various types of stop consonants. VOT was initially defined as "the timing relation between voice onset and the release of occlusion" (Lisker & Abramson, 1964, p. 387). This measure was used to distinguish between voiced, unaspirated voiceless, and aspirated stops (see also P. A. Keating, 1984): a voiced stop is characterised by a voicing lead through much or all of its closure and release; an unaspirated voiceless stop exhibits a VOT of 0 ms or a short, briefly aspirated lag; and an aspirated voiceless stop has a larger voicing lag with aspiration throughout.

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Aspirated voiceless stops thus have a longer VOT than unaspirated ones due to the delay before the vocal cords start vibrating, while voiced stops can have short or even negative VOT values. Given that most languages exhibit some form of voicing contrast (Dryer & Haspelmath, 2013; Ladefoged & Maddieson, 1996; Maddieson, 2013), VOT is most often a reliable measure of the difference between voiceless–voiced pairs like /p/ and /b/ in the word-initial sounds of *pat* vs. *bat* in English, and *pas* "belt" vs. *bas* "bass" in Slovenian. For instance, English voiced and (aspirated) voiceless stops like /b/ and /p/ are characterised by short and long lag, respectively, whereas Slovenian voiced /b/ and (unaspirated) /p/ should exhibit a voicing lead and a short lag, respectively. Since this study is limited to the voiceless series, our focus is on the difference between L1 (Slovenian) unaspirated voiceless stops, and L2 (English) aspirated ones.

VOT is also affected by the place of articulation: stops produced at the front of the mouth, such as /p/, generally have shorter VOTs than those produced at the back of the mouth, such as /k/ (see, among others, Cho & Ladefoged, 1999).

In their seminal 1964 study, Lisker and Abramson examined 11 languages, categorising them into three groups based on the number of stop categories at each place of articulation. English was placed in the two-category group (voiced and voiceless labial, alveolar, and velar stops), with its stops mostly falling within the +10 and +75 ms ranges (Lisker & Abramson, 1964, p. 403). The study also measured the VOT of stops in sentences, observing the "effect of embedding the stops in running speech" (Lisker & Abramson, 1964, p. 413). This effect was noted in English as well, particularly in categories with short voicing lag. Since the focus of this paper is on the voiceless series, the relevant portion of the data acquired for English is presented in Table 1.

Table 1. VOT of English voiceless stops (cf. Lisker & Abramson, 1964, p. 394) in isolated words and in connected speech.

	/p/		/t/		/k/	
	Isolated	**Connected**	**Isolated**	**Connected**	**Isolated**	**Connected**
Mean	58	28	70	39	80	43
Range	20–120	10–45	30–105	15–70	50–135	30–85
N	102	24	116	26	84	25

As illustrated in Table 1, the measurements for VOT in isolated words differ significantly from those in connected speech. This variation is typically attributed to factors such as speech rate, place of articulation, and phonetic context (Lisker & Abramson, 1964, 1971; Yao, 2009). Kessinger and Blumstein (1998), for instance, established that the duration of VOT in voiceless stop plus sound sequences increases if the speech rate slows. In some cases, these effects can be language-specific: the same authors (Kessinger & Blumstein, 1997) compared Thai, French and English and found that the short lag category remained stable at different speaking rates in all three languages, whereas long-lag VOT in Thai and English and pre-voiced stop consonants in Thai and French were affected (the values became shorter), but with only little overlap between voicing categories. Smiljanić and Bradlow (2008, p. 94) also found different speech rate effects in English and Croatian, but their results remain in line with their observation that the findings of various studies show that "speakers and listeners rely on rather local timing relations to allow for rate-independent speech processing".

More than fifty years after the original study, and following extensive research on VOT across a number of languages, Abramson and Whalen (2017, p. 79) reiterated that "[v]oicing categories in many of the world's languages are captured as differences in VOT […]". They proposed some amendments to the original definition of VOT to better analyse stops in medial positions, fricatives, and other contexts, but since these changes fall outside the scope of the present research, they will not be discussed further here.

While no Slavic languages were included in the 1964 study, several such studies now exist and show that VOT is also a relevant acoustic measure in Slavic languages. For instance, Ringen and Kulikov (2012) studied monolingual speakers of Russian and identified pre-voicing in utterance-initial lenis stops, while fortis stops were pronounced as voiceless unaspirated, with a short positive VOT. Smiljanić and Bradlow (2008, p. 92) also describe Croatian voiced and voiceless stops as "characterized by prevoicing and short lag, respectively", and Čubrović (2013, p. 15) shows that Serbian is a "typical short-lag language". The same has been observed for Polish, which also contrasts pre-voiced /b d g/ with voiceless unaspirated /p t k/ (P. A. Keating, 1984; P. A. Keating et al., 1981). For Czech, Kaňok and Novotný recently observed a short lag for the voiceless series and a long lead in the voiceless series, with male speakers in their study producing longer VOT in voiceless plosives /p/ and /t/ (Kaňok & Novotný, 2019, pp. 99–100). For Bulgarian, Andreeva and Wolska (2011) confirm that /p t k/

exhibit short-lag VOT. Bulgarian, Russian and Polish are also listed among the "lead vs. short lag" languages by P. Keating et al. (1983, p. 280), who explain that such VOT is typical of languages with two contrasting (unaspirated) voiced and voiceless categories in the initial position.

VOT can also be used to examine the extent of transfer in L2 acquisition. It has been observed that speakers of a foreign language do not always recreate the VOT distinctions typically present in the speech of native speakers. Nevertheless, L2 speakers may still create a phonetic distinction in VOT between the native and foreign languages (for a study of English speakers acquiring Japanese as L2, see Harada, 2007; for a comparison of English/French learners, see Flege, 1987; for findings on Croatian English, see Horga & Mildner, 1999). While it has been established that the degree of VOT covariation observed in the productions of native speakers may still be mirrored in the non-native production of the same language (e.g., L2 English speakers in the study by Chodroff & Baese Berk, 2019), other outcomes are also possible. For example, some research shows that both assimilation and dissimilation are possible, i.e., L2 speakers may observe the L1 phonetic norms (Flege, 1991) or diverge from them (Flege, 1987).

In the context of Slavic languages, Jakovljević (2012) provides evidence of transfer in the production of English word-initial stop consonants by Serbian speakers. This finding partly contrasts with Čubrović's (2011) earlier study, which suggested that Serbian EFL learners can acquire the VOTs necessary for native-like articulation of English stops. Similarly, Koffi and Abat (2014) reported the transfer of negative VOT to L2 English among Montenegrin speakers. Furthermore, Wieczorek and Rojczyk (2024) found that Polish students largely failed to imitate English VOT.

Slovenian, on the other hand, has not been researched in this regard. In contrast to English, it is described as a language that lacks aspirated stops, so the difference between short-lag and long-lag stops is not salient (cf. Stemberger & Chávez-Peón, 2025, p. 126). Voiceless stops occurring in word-initial stressed syllables are realised as unaspirated in Slovenian and aspirated in English, with their places of articulation roughly the same: bilabial, (dental-)alveolar and velar (see Toporišič, 2004, pp. 78–86, for Slovenian, and Cruttenden, 2014, pp. 173–181, for English).

Following the literature presented above, the objective of this study is to measure the VOT of English and Slovenian voiceless consonants produced by native speakers of Slovenian that occur in word-initial stressed syllables. To the best of our knowledge, such data has not been previously collected. Furthermore, given

that the subjects of this analysis are native speakers of Slovenian, the study also examines the potential language transfer of Slovenian VOT features to the articulation of English stops. The research questions are as follows.

Research question 1 (RQ1): Do VOT measurements of voiceless consonants in word-initial stressed position in the connected speech of Slovenian speakers exhibit short VOT lag and differ depending on the place of articulation?

Research question (RQ2): Is there a difference between the VOT values in the realisations of voiceless stops in the speakers' L1 Slovenian and L2 English?

Research question (RQ3): Are there significant differences between VOT measurements pertaining to different speakers?

2. Methodology

In alignment with the objective of this study, VOT measurements of English and Slovenian voiceless consonants in word-initial stressed syllables were collected. The measurements were conducted using publicly available recordings of connected speech.[1]

The recordings feature a female (Speaker 1) and a male speaker (Speaker 2), both native Slovenian speakers and university-educated media professionals who co-host a podcast on media, new technologies and future trends. The hosts act as interviewers in discussions with professionals working in relevant fields. While most of the episodes are recorded in Slovenian, entire episodes are recorded in English when the guests are not Slovenian speakers. Consequently, the recordings used in the analysis are authentic and textually equivalent (maintaining the same format and topics), with the same two speakers conducting the discussions in either Slovenian or English.

To acquire the amount of data sufficient for statistical analysis (at least 30 measurements per consonant per language), nine episodes of the podcast

[1] Due to the lack of data on VOT in Slovenian, a small-sample pilot study of VOT in isolated Slovenian words was conducted prior to this study. The preliminary findings indicate that Slovenian exhibits similar characteristics to other Slavic languages: the voiceless and voiced pairs are affected by the place of articulation, and the voiced series is in the negative range. The mean VOT values collected were as follows: /p/: 23 ms, /t/: 28 ms, /k/: 47 ms; /b/: -147 ms, /d/: -126 ms, and /g/: -108 ms.

were analysed, resulting in the collection of 712 VOT measurements. Specifically, the podcasts were saved in WAV format (44.1 kHz, 32 bit) and imported into the Praat speech analysis software tool (Boersma & Weenink, 2025). In Praat, each relevant syllable (word-initial, stressed, followed by a vowel) was manually located, and the VOT measurement was extracted.

The measurements were entered in an Excel spreadsheet and statistically analysed with regard to the number of items, frequency mean values, and standard deviation. The speakers' articulatory rates (in syllables per second, sps) were also calculated based on samples of their speech from different episodes. Finally, various groups of data were also compared using the two-tailed unpaired t-test method to determine if there was a significant difference between the means of the two groups.

3. Results and discussion

3.1. Speaker 1

Table 2 presents an overview of the measurements for the female speaker, whose articulatory rate is approximately 5.36 syllables per second (sps) in Slovenian, and 4.46 sps in English.[2]

Table 2. VOT values (in ms) in Slovenian and English for Speaker 1.

	/p/		/t/		/k/	
	Slo.	**Eng.**	**Slo.**	**Eng.**	**Slo.**	**Eng.**
Mean	15	19	21	28	38	46
SD	8	11	5	10	10	19
N	84	47	116	69	66	52

[2] The articulatory rates for both speakers (see 3.1 and 3.2) were calculated based on samples of analysed speech. Each of the four samples (this includes two speakers using two languages) is about ten minutes long and contains around 1,000 syllables. The collected data is in line with the findings of previous research – for more on Slovenian, see Scuteri (2019), and for a recent discussion on English, see Plug et al. (2021). The author would like to thank the reviewers for their useful comments regarding speech/articulatory rates.

The data presented in Table 2 indicate a progressive increase in VOT mean values as the place of articulation moves towards the back of the mouth in both in Slovenian and English utterances. This trend is expected and aligns with similar studies conducted on other languages (e.g., Cho & Ladefoged, 1999; Harada, 2007; Lisker & Abramson, 1964). The data have also been statistically examined using a two-tailed unpaired t-test, revealing significant differences between the consonant pairs /p t/, /t k/, and /p k/ in both Slovenian and English ($p < 0.05$). It should be noted that the standard deviation (SD) values observed in the Slovenian measurements were lower, indicating smaller variation, which may be attributed to the speaker's native proficiency in Slovenian.

A comparative analysis of Figures 1 and 2, below, reveals almost no overlap between individual stops within the interquartile range for Slovenian, with distinctly defined boundaries between VOT ranges. This delineation is less pronounced in English, and the VOT interquartile ranges for English are both greater and higher than those for Slovenian.

It is also noteworthy that the VOT ranges for L2 English in our data set are smaller than those reported by Lisker and Abramson (1964) for native English speakers in connected speech (see Table 1). This reduction in VOT range for L2 English, as produced by Speaker 1, is primarily due to the upper limit of the range being lower, i.e., Speaker 1's longest VOTs in her L2 English are generally shorter than those of a native speaker.

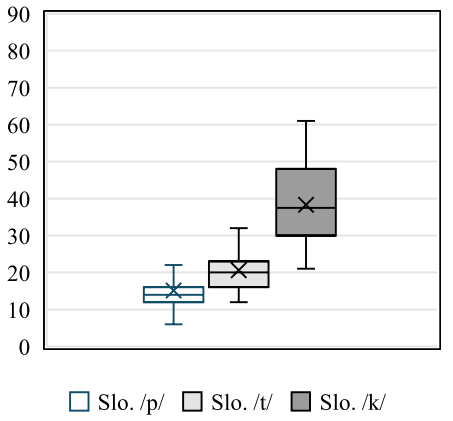


Figure 1. Slovenian VOT values for Speaker 1.

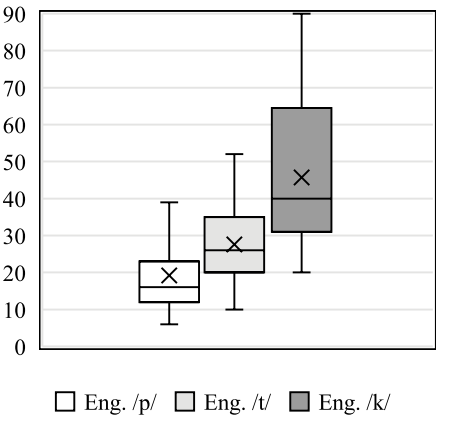


Figure 2. English VOT values for Speaker 1.

The findings indicate that Speaker 1's VOT values in L2 English fall somewhere between those for Slovenian and those for native English speakers. The L2 norm with respect to VOT is thus not fully reached; however, the speaker clearly distinguishes between VOT ranges in L1 and L2. Some cross-linguistic parallels can be drawn if we consider Harada's (2007) work on Japanese, the similar findings reported for Serbian/Serbian English by Čubrović (2011) and Jakovljević (2012), as well as the findings for Croatian English in Horga and Mildner (1999, p. 757).

A two-tailed unpaired t-test was conducted to compare the VOT values for homorganic consonants produced by Speaker 1 in L1 and L2. The results revealed significant differences in the VOT values for each of the observed stops. Notably, the most pronounced difference was observed in the (dental-) alveolar /t/, indicating an extremely significant variation. These findings suggest a systematic phonetic shift from one language to the other. Thus, while the difference between short-lag and long-lag stops is not salient in Slovenian (Stemberger & Chávez-Peón, 2025, p. 126), Speaker 1 shows an awareness of the difference and aims to approximate a phonetic distinction in VOT between L1 Slovenian and L2 English (cf. Flege, 1987, p. 59).

Additionally, it should be noted that Speaker 1's articulatory rate is higher in Slovenian. It is feasible to claim that the lower articulatory rate in English (compared with the data in Plug et al., 2021) is related to the latter being her L2. The potential effect of the speaker shortening her VOTs in Slovenian more than in English (cf. Kessinger & Blumstein, 1998; Smiljanić & Bradlow, 2008) may also be a factor in interpreting the longer VOT ranges in the latter.

3.2. Speaker 2

Table 3 presents an overview of the measurements for the male speaker, whose articulatory rate is around 6.05 sps in Slovenian, and 4.63 sps in English.

Table 3. VOT values (in ms) in Slovenian and English for Speaker 2.

	/p/		/t/		/k/	
	Slo.	**Eng.**	**Slo.**	**Eng.**	**Slo.**	**Eng.**
Mean	14	19	26	31	43	46
SD	5	10	6	11	12	14
N	50	46	73	37	31	41

The findings for Speaker 2 largely correspond to those for Speaker 1 (see 3.1). The data presented in Table 3 thus show a progressive increase in VOT mean values as the place of articulation moves posteriorly, and this observation holds for both Slovenian and English measurements. These differences have also been statistically analysed with a two-tailed unpaired t-test, demonstrating significant variations between /p t/, /t k/, and /p k/ in both languages ($p < 0.05$). The amount of variation in the data set (SD) is again less pronounced in the Slovenian utterances.

Furthermore, a comparison of Figures 3 and 4, below, indicates that the boundaries between the three consonants are more clearly defined in Slovenian, whereas the English data overlap to a greater extent. The VOT interquartile ranges for Speaker 2's English are both greater and higher than those for Slovenian. The VOT ranges for L2 English ranges are also smaller and lower (in upper limit of the range) than those reported for native English speakers, which also corresponds with the measurements collected for Speaker 1.

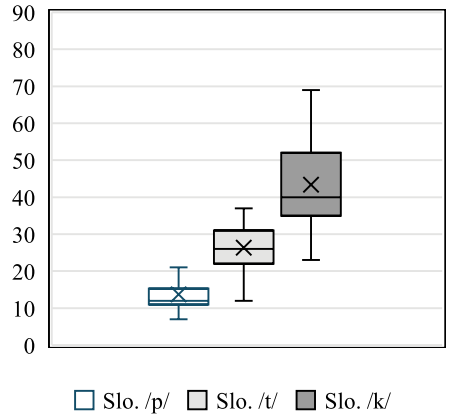


Figure 3. Slovenian VOT values for Speaker 2.

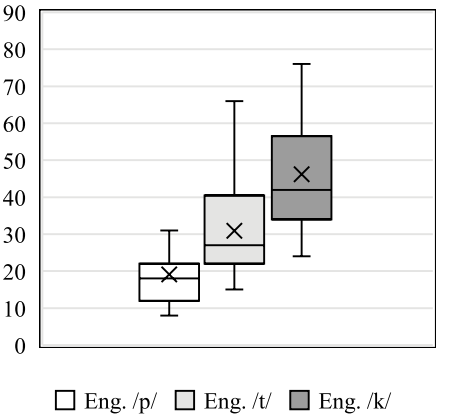


Figure 4. English VOT values for Speaker 2.

A two-tailed unpaired t-test comparing the VOT values for homorganic consonants produced by Speaker 2 in L1 and L2 revealed significant differences in VOT values for /p/ and /t/, with the most pronounced and extremely significant difference observed for /p/. Conversely, the VOT values for /k/ in Slovenian and English for Speaker 2 did not show significant differences.

Compared to Speaker 1, the findings suggest a less pronounced phonetic shift from one language to the other.

Speaker 2's articulatory rate is also higher in his L2 English than in his L1 Slovenian. Considering the potential shortening effect of higher articulatory rates on VOTs (see 3.1 for a similar discussion on Speaker 1), we can again conclude that this may be a factor contributing to the divergence from the L1 norms presented for L2 English.

3.3. Slovenian (L1) data

A two-tailed unpaired t-test was performed to compare the VOT measurements of the two speakers within the same language. For Slovenian (L1), the null hypothesis posited that the VOT values for voiceless stops with the same place of articulation would not exhibit statistically significant difference between the two speakers.

The hypothesis was supported only for the bilabial stop /p/, indicating that Speakers 1 and 2 produce this consonant with statistically comparable VOT values. Conversely, the hypothesis was rejected for the dental-alveolar stop /t/ and velar stop /k/. Specifically, the difference in VOT for /t/ was found to be extremely statistically significant ($p < 0.05$), whereas the difference for /k/ was statistically significant though not at the level of high or extreme significance. Also noteworthy is that the female speaker generally articulates the stops with shorter VOTs, which may be related to gender. For instance, Kaňok and Novotný (2019) observe a longer duration of VOT in Czech /p/ and /t/ in men. However, confirming this observation is beyond the design of the present study.

The final VOT measurements, including the interquartile ranges for L1 Slovenian of Speakers 1 and 2 (S1 and S2), are presented in Table 4. Based on the results of the t-tests, the data for /t/ and /k/ is presented separately for each speaker.

Table 4. Slovenian (L1) VOT data for Speakers 1 (S1) and 2 (S2).

	/p/	/t/		/k/	
	S1+S2	**S1**	**S2**	**S1**	**S2**
Mean	15	21	26	38	43
Interquartile range	11–16	16–23	22–31	30–48	35–52
SD	7	5	6	10	12
N	134	116	73	66	31

3.4. English (L2) data

A two-tailed unpaired t-test was also performed to compare the VOT measurements of the two speakers when they conversed in English. The null hypothesis posited that the VOT values for voiceless stops with the same place of articulation would not exhibit statistically significant differences between the speakers.

The null hypothesis was supported for all observed consonants, indicating that the two speakers produced the L2 English stops without any significant differences in VOT. Consequently, Figure 5 presents the combined L2 English VOT data for Speakers 1 and 2, reflecting the observed similarities in their production patterns.

Interestingly, the different degrees of variation between Slovenian (see 3.3) and English VOT data are in line with the observation in Chodroff and Baese-Berk (2019, p. 664), who report weak correlations in means and SDs in L1 speakers, and moderate to strong ones across L2 speakers of English.

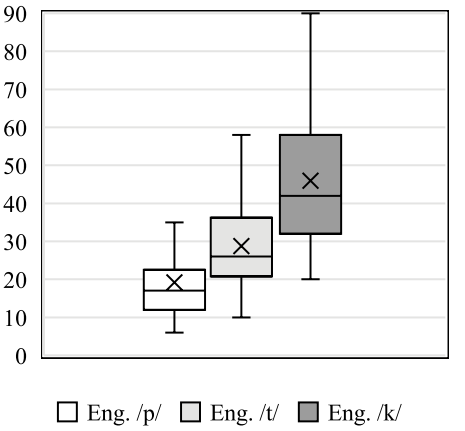


Figure 5. English VOT values for Speakers 1 and 2 (combined data).

The combined VOT measurements, including the interquartile ranges for L2 English of Speakers 1 and 2, are presented in Table 5.

Table 5. English (L2) VOT data for Speakers 1 and 2.

	/p/	/t/	/k/
Mean	19 ms	29 ms	46 ms
Interquartile range	12–23 ms	21–36 ms	32–58 ms
SD	11	11	17
N	93	106	93

4. Conclusion

Based on the results and discussion presented above, the following conclusions can be drawn regarding the research questions.

Short-lag VOT and the effect of the place of articulation in Slovenian (RQ1): The VOT measurements are shorter for Slovenian unaspirated voiceless stops than for English aspirated ones. It was also established and statistically confirmed that both speakers exhibited a progressive increase in VOT mean values as the place of articulation moved towards the back of the mouth. This trend was observed in both Slovenian (L1) and English (L2) utterances.

Voiceless plosives in L1 and L2 (RQ2): Both speakers realised the voiceless plosives differently when switching from their L1 Slovenian to L2 English. Notably, a phonetic shift to higher VOT ranges was detected in the English productions compared to their L1. However, the targeted VOT ranges were somewhat lower (in the upper limit of the range) than those reported for native English speakers. Additionally, the variation in data and the overlap between the observed stops were greater in English than in Slovenian, indicating a degree of inconsistency in the production of L2 stops. Nevertheless, both speakers consistently attempted to distinguish the English aspirated stops from the unaspirated ones in their L1. These findings suggest that the speakers only partially rely on their L1 Slovenian in their production of English voiceless stops. The effect of negative language transfer is thus present but minimal, and it does not present an obstacle to successful communication.

Comparison of speakers (RQ3): A comparison of the two speakers revealed that their VOT ranges differed in Slovenian, with the female speaker's ranges being slightly lower. The t-test analysis showed that the difference was significant

for /t/ and /k/, but not for /p/. This variation among speakers of the same language is not unexpected. More surprising, however, was the data for English, where the two speakers targeted the same VOT ranges, indicating that their L2 production with the regard to VOT was statistically indistinguishable. Despite this, the English data exhibited more general variation and overlap between the individual consonants than the Slovenian data. This observation warrants further research involving more speakers.

The findings present new data on Slovenian and highlight the influence of native language on VOT values and the phonetic shifts that occur when speakers produce stops in L2. The results also underscore the importance of considering individual speaker differences when analysing phonetic data. Further research should include a larger sample of speakers and a broader range of measurements. Additionally, the scope of the study should be extended to include voiced stops, with a separate experiment also focusing on VOT measurement in isolated words.

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Czas rozpoczęcia dźwięczności (VOT) w realizacji bezdźwięcznych spółgłosek zwartych w języku słoweńskim jako ojczystym (L1) oraz jego transfer do angielskiego jako języka obcego (L2)

W artykule badane są cechy czasu rozpoczęcia dźwięczności (VOT) u rodzimych użytkowników języka słoweńskiego podczas realizacji bezdźwięcznych spółgłosek zwartych w języku słoweńskim i angielskim. Opierająca się na podstawowych ustaleniach Liskera i Abramsona (1964) analiza ma na celu wypełnienie luki w literaturze dotyczącej VOT w odniesieniu do fonetyki języka słoweńskiego, szczególnie w kontekście przyswajania języka obcego (L2). Wykorzystując nagrania mowy ciągłej dwóch rodzimych użytkowników języka słoweńskiego biegle posługujących się oboma językami, przeprowadzono pomiary VOT dla bezdźwięcznych spółgłosek zwartych /p/, /t/ i /k/ w pozycji inicjalnej wyrazu, w sylabach akcentowanych. Wyniki wykazują, że u obu badanych obserwuje się stopniowy, statystycznie istotny wzrost wartości VOT w miarę przesuwania się miejsca artykulacji od dwuwargowego do miękkopod-

niebiennego, zarówno w języku ojczystym (L1), jak i w języku obcym (L2). Warto zauważyć, że choć badani zachowują podobne, lecz wyraźnie odmienne zakresy VOT w języku słoweńskim, ich realizacje w języku angielskim wykazują większe zbieżności i cechują się wyższymi wartościami VOT niż w języku ojczystym, co wskazuje na adaptacyjną reakcję fonetyczną na środowisko języka obcego (L2).

Słowa kluczowe: czas rozpoczęcia dźwięczności (VOT); język słoweński; język angielski; VOT w mowie ciągłej; transfer językowy

Voice Onset Time (VOT) in L1 Slovenian voiceless stops and its transfer to L2 English

The study investigates the Voice Onset Time (VOT) characteristics of Slovenian native speakers producing voiceless plosives in Slovenian and English. Building on foundational research by Lisker and Abramson (1964), the analysis aims to fill a gap in VOT literature regarding Slovenian phonetic features, particularly in the context of second language (L2) acquisition. Utilising connected speech recordings from two native Slovenian speakers fluent in both languages, VOT measurements were obtained for word-initial voiceless stops /p/, /t/, and /k/ in stressed syllables. The results reveal that both speakers exhibit a progressive, statistically significant increase in VOT as the place of articulation shifts from bilabial to velar in both L1 and L2 contexts. Notably, while the speakers maintain similar but distinct VOT ranges in Slovenian, their English productions align more closely in VOT ranges higher than those in their L1, indicating an adaptive phonetic response to the L2 environment.

Keywords: voice onset time (VOT); Slovenian language; English language; VOT in connected speech; language transfer

Andrej Stopar (andrej.stopar@ff.uni-lj.si) – adiunkt w Katedrze Anglistyki na Wydziale Humanistycznym Uniwersytetu w Lublanie (Słowenia). Prowadzi zajęcia z zakresu językoznawstwa ogólnego, leksykologii, przekładu, intonacji wypowiedzi oraz zagadnień związanych z językiem i kulturą. Zainteresowania naukowe: relacje między językiem angielskim a słoweńskim, ze szczególnym uwzględnieniem fonetyki, fonologii, testowania językowego oraz leksykologii.

Andrej Stopar (andrej.stopar@ff.uni-lj.si) – Associate Professor in the Department of English at the Faculty of Arts, University of Ljubljana (Slovenia). He teaches courses on general linguistics, lexicology, translation, discourse intonation, and language and culture. Research interests: the interplay between English and Slovene, with an emphasis on phonetics, phonology, language testing, and lexicology.

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