Could You Say [læpˈ tɒpˈ]? Acquisition of Unreleased Stops by Advanced French Learners of English Using Spectrograms and Gestures

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Abstract: The present study analyses the production rates of stop-unrelease amongst advanced French learners of English before and after training. Although stop-unrelease may be regarded as a minor issue in English pronunciation teaching, it has received some attention in recent years. Earlier studies showed that amongst "phonetically naive English listeners", the lack of release of /p/, /t/ and /k/ leads to lower identification scores. The present study analyses the speech of 31 French university students majoring in English to measure the efficiency of an awareness approach on the production of stop-unrelease. The experiment comprised three phases with a test and a control group. During Phase 1, both groups were asked to read pairs of words and sentences containing medial and final voiceless stops. We chose combinations of two identical stops (homorganic) or stops with different places of articulation (heterorganic), as well as stops in utterance-final position. Namely, *wait for me at that table over there*, *that pan*, or *I like that truck*. In Phase 2, one group watched an explanatory video to increase awareness on stop-unrelease in English before reading Phase 1 words and sentences a second time. The remaining group was the control group and did not receive any training. Among the participants, 17 read a French text containing pairs of stops in similar positions to those in the English one, which served as an L1 baseline. In total, six students continued until Phase 3 (reading the same stimuli a month later; three in the control group and three in the test group). The results showed that sentence-final stops were overwhelmingly released (above 90%) in both English and French in Phase 1. Training had a significant impact on sentence-final stop-unrelease ($p < 0.001$), which rose from 9.65% to 72.2%. Progress was also visible in other contexts as in heterorganic pairs of stops. Based on these results, we strongly recommend the combined use of spectrograms and gestures to raise awareness in a classroom or for online learning so as to reach multiple learner profiles and further increase efficiency in pronunciation learning.

Keywords: stop-unrelease in French; L2 learner production; stop-unrelease in English; spectrograms for pronunciation; gestures in learning

1. Introduction

Cross-language phonetic phenomena are often examined through the prism of Flege's trifold taxonomy: "from the standpoint of Ll, the phones in an L2 may be taxonomized acoustically as 'identical', 'similar' or 'new'" (Flege 1987, p. 48). When the realisation of a phoneme in an L2 is acoustically 'similar' to that of an L1 phoneme, i.e., what French /u/ is to English speakers, language learners are less likely to place each /u/ in different phonetic categories. This phenomenon is known as *equivalence classification* (Flege 1987) and may prevent learners "from making effective use of auditorily accessible acoustic differences between phones in L1 and L2" (Flege 1987, p. 50). This was part of what Flege called the Speech Learning Model (Flege 1995). Flege and Bohn's revised Speech Learning Model (henceforth SLM-r) suggests that the quality of input in an L2 may help learners to overcome such difficulties (Flege and Bohn 2021). These differences mainly

concern acoustic or articulatory characteristics of phonemes. However, differences also lie in the allophonic distribution of such phonemes. In this study, we hypothesise that the equivalence classification also applies to the way in which learners classify allophonic distributions that occur in both their L1 and L2, such as unreleased stops—which are found in French and in English. Unreleased stops, i.e., stops lacking audible release, are frequent in word-medial position in both languages but are reported to be less frequent in word-final position in French (Abercrombie 1967). This may lead French learners of English to use equivalent allophonic distributions of stops in both languages.

The present study explores the impact of an awareness-raising approach on stop-unrelease in the speech of advanced French learners of English. Awareness-raising in second-language speaking, i.e., the facilitation of "conscious knowledge of the facts learned about a language" through various means (Crawford 1987, p. 109), has been shown to have a significant and long-term effect on L2 speech production (Svalberg 2007). Our awareness-raising approach includes a research-based explanation of the above-mentioned allophonic distribution to the participants of the study, a presentation of unreleased stops from an articulatory point of view and through the visualisation of the acoustic properties of stops on spectrograms. The approach includes the use of gestures during the production of stops to maximise the efficiency of the training. Although using various approaches may not enable us to determine which approach would work best regarding the allophonic acquisition of stop-unrelease, Shams and Seitz (2008) advocate for more multisensory modalities in learning rather than a "single modality in learning" since the former "better approximate natural settings and [are] more effective for learning" (p. 411). We therefore decided to opt for a more "natural" and "multisensory" training environment.

A key tool in our awareness-raising approach is the use of spectrograms. Quintana-Lara (2014) pointed at the efficiency of spectrograms in the pronunciation training of /ɪ/ vs. /iː/ amongst Spanish advanced learners of English through the observation of F1/F2 values produced by the learners and by native speakers. In the present study, spectrograms were deemed a good learning tool since utterance-final stops on a spectrogram are easier to interpret than are F1/F2 values for vowels. If stops are released, a burst is visible, and if they are not released, no burst is observable. Such a binary interpretation, albeit simplistic, is accessible to any language learner[1]. However, although they may contribute to raising awareness on stop-unrelease, spectrograms may not help learners to master it from an articulatory point of view. Moreover, the tool cannot be used comfortably in natural conversations since observing the spectrogram during a conversation inevitably stops the flow of communication between speakers. We therefore suggest using hand gestures during the speech production phase, as they are often used in natural speech (Krauss et al. 1995) and should thereby disrupt a conversation to a lesser extent than spectrograms. Hand gestures are also known to be efficient tools in language learning and can foster progress in various learning situations (e.g., Kelly et al. 2002; Goldin-Meadow 2003). More specifically, they may facilitate the acquisition of new L2 sounds. Xi and colleagues tested the efficiency of gestures in the acquisition of Mandarin stops and affricates amongst Catalan learners of Chinese (Xi et al. 2020). The results indicate that appropriate gestures "mimick[ing] the phonetic properties" of the sounds as closely as possible helped to improve the learners' productions of these stops and affricates. When dealing with sub-phonemic phenomena like unreleased stops or the aspiration of stops in L2 English, gestures can prove more efficient than mere imitation (Amand and Touhami 2016) amongst intermediate French learners of English ranging from secondary school French students to French teachers of English. It did not include university students majoring in English. Hence, the purpose of the present study is to measure the acquisition of stop-unrelease amongst advanced university students of English through awareness-raising via a multisensory learning material, i.e., spectrograms and gestures.

Section 2 briefly summarises the articulatory and acoustic properties of stop-unrelease, lists previous studies analysing stop-unrelease in French and English as an L1 and an L2. Section 3 presents the research questions followed by the hypotheses. Section 4 covers the

material and methods used in the study. In the results given in Section 5, the rates of stop-unrelease are analysed by language, syntactic context and learning phase. A discussion of the results is provided in Section 6 and is followed by a conclusion (Section 7). The stimuli in French and English are provided in Appendices A and B respectively.

2. An Overview of Stops and Stop-Unrelease

2.1. Articulatory Properties of Stop Consonants

Laver (1994, p. 205) provides a detailed definition of stops, which are realised in three phases: (1) the closing phase: "articulatory transition towards complete closure", (2) the closed phase: from the moment when "full closure begins to the moment it ends", and (3) the release phase: "the compressed air escapes to the atmosphere with a small but audible explosion", also known as "stop burst". For some stops, the last phase is missing, which is the case of unreleased stops (Laver 1994, p. 559).

Voiceless unreleased stops can be defined as "lacking an audible explosion at the release phase" (Laver 1994, p. 359)—IPA: [p˺], [t˺] and [k˺]. In English, stop-unrelease is optional in utterance-final position (Laver 1994, p. 43). Laver adds that "two oral stops can optionally be incomplete", i.e., at least one of the three phases is missing, "even when a word-boundary intervenes" (Laver 1994, p. 359). When two subsequent stops have the same place of articulation, the pair is homorganic, with the second one lacking the onset phase (Laver 1994, p. 359): *a ba**ck** **g**arden*, *a ba**ckc**ourt*. Heterorganic pairs of stops have different places of articulation: *sta**ck**ed*, *a ba**ck** **d**oor*. The next section outlines the main acoustic properties of stop-unrelease.

2.2. Acoustic Properties of Unreleased Stop Consonants: Looking for Shadows in the Vowel

In this study, only voiceless stops were examined because they are known to provide more acoustically measurable release bursts than voiced plosives (Crystal and House 1988; Byrd 1996). Storto and Demolin (2002) provide a clear and illustrated description of the general acoustic specificities of stop-unrelease: there should be no burst but the presence of formant transitions in the preceding vowel is indicative of an unreleased stop. By contrast, "when no consonant follows the final vowel…there are no observable formant transitions" (Storto and Demolin 2002, p. 489. Spectrographic illustrations, p. 490). Figure 1 provides a clear illustration of stop-unrelease in the noun phrase *a hip* by participant TNA26F (L1 French) from the present study (before and immediately after a training session on stop-unrelease formant transitions are clearly visible on the right hand-side of the vowel).

After a brief definition of stop-unrelease, the following section summarises research on stops in French and English as an L1.

2.3. Voiceless Stop-Unrelease in L1: French and English

2.3.1. French

To our knowledge, very little research has been carried out on stop-unrelease in French. van Dommelen (1983, 1985) analysed the perception of voicing in stops in word-final and word-medial position by native speakers of French. He only very briefly mentions that the voiced/unvoiced distinction amongst unreleased stops in word-medial position seems to increase discrimination error rates (van Dommelen 1985, p. 110). Kohler and Künzel (1979) deal with stops in standard French, but unreleased stops are not analysed in depth. Abercrombie posits that unrelease is unlikely to occur for the first stop of two consecutive stops in French and considers the French word *apte* as "distinct from English *apt*" in that respect (Abercrombie 1967, p. 147) since the first stop is expected to be unreleased in English. However, this affirmation lacks empirical support from experimental research. Therefore, we decided to record a sample of French native speakers pronouncing stops in different contexts (medial and final) to serve as a baseline for this study.

2.3.2. English

Davidson's study on spontaneous American English from the StoryCorps corpus (monologues or interviews) showed that unrelease occurred between 50 and 60% of the time in pre-pausal positions (Davidson 2011). She observed slightly higher rates of unrelease than those in Byrd's study on American English stops in sentence-final position (TIMIT database, read speech by 630 speakers: 1130 oral stops were found across 6300 sentences). Rates of unrelease amounted to 50.5% for bilabial stops, 43% for alveolars and 16.89% for velars (Byrd 1992, p. 37)[2]. Hence, the purpose of this study is not so much to train French learners of English to systematically unrelease their stops in sentence-final position but to help them to master an allophonic variation that is more common in English in sentence- or word-final position than what seems to be the case in French. The next section outlines studies on the acquisition of stop-unrelease in English as a second language.
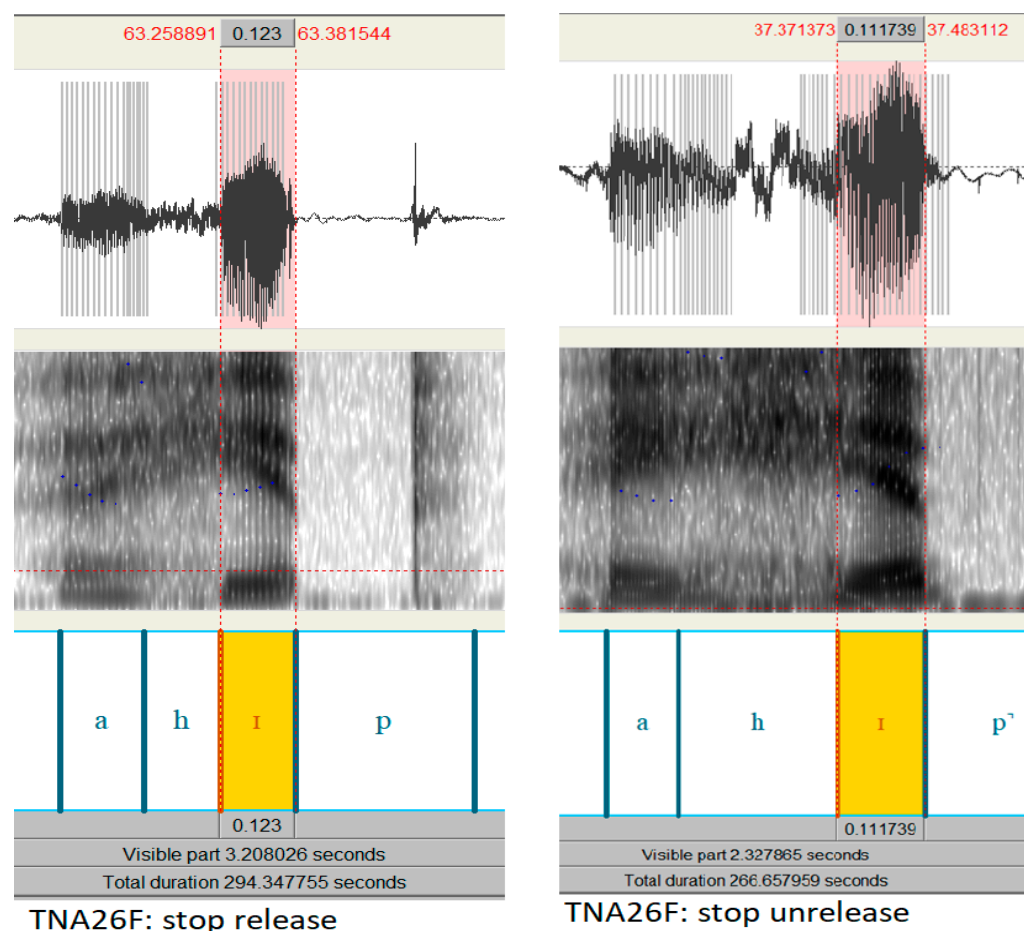

Figure 1. Spectrographic representation of *a hip* by the speaker TNA26F (L1 French, L2 English). Left: pre-training (rec1), a burst is visible along with formant transitions in the preceding vowel [ɪ]. Right: post-training (rec2), an example of the absence of burst until the next phrase *a hit*, but the presence of formant transitions in [ɪ], thereby confirming the presence of stop-unrelease.

2.4. Previous Studies on Stop-Unrelease in L2

A study by Rojczyk et al. (2013) indicated that Polish learners of English could increase the proportion of stop-unrelease in English when imitating a native speaker, but when the imitation task was preceded by a distraction (read digits after auditory exposure), percentages of stop-unrelease dropped considerably. They nonetheless indicate that the presence of an unreleased allophonic variant in Polish for homorganic pairs of stops facilitates the learners' imitation of unreleased stops in L2 English (see Rojczyk 2008 on Polish stops). The stimuli were limited to nine pairs of words (see Rojczyk et al. 2013, p. 7).

Bergier's longitudinal study ([Bergier 2010](#), [2014](#)) showed that proportions of unreleased stops within a sentence could rise amongst Polish university learners of English via an awareness approach. Šimáčková and Podlipský also investigated unreleased English stops in stop-stop sequences amongst advanced Czech learners of English, this time through the prism of "local fluency i.e., word-to-word transitions in connected speech" ([Šimáčková and Podlipský 2015](#), p. 139).

Stop-unrelease in English is also found in word-final pre-pausal position. Another study by [Tsukada et al.](#) ([2005](#)) measured the proportion of stop-unrelease in word-final position amongst 90 L1 Korean speakers of English (children and adults) living in the United States. Korean (voiceless) stops in pre-pausal word-final position are not released, leading to higher proportions of stop-unrelease in Korean speakers of English than amongst native speakers of English. This suggests that non-contrastive phonetic detail in an L1 may be transferred into an L2. In this study, no particular training was chosen to modify the learners' allophonic variation patterns in word-final stops in English.

[Amand and Touhami](#)'s ([2016](#)) pilot study compared two types of training (distracted imitation vs. an awareness-raising video) to investigate the acquisition of stop-unrelease amongst French learners of English in pairs of stops and pre-pausal word-final stops. The study involved a limited number of participants distributed in three cohorts based on language proficiency—secondary school children, adults having learnt English until the end of secondary school and French teachers of English. Participants produced stops in English only (pre-training and post-training). The results showed that there were significantly higher rates of stop-unrelease across word boundaries than in final stops amongst French learners of English, which suggests that pre-pausal word-final stops in L1 French and L2 English should be investigated further.

3. Research Questions and Hypotheses

In the present study, we wish to examine stop-unrelease in pairs of stops and in pre-pausal position in both French and English. We want to assess to what extent advanced French learners of English classify the allophonic variation patterns of stops as equivalent to those in their L1 (as per [Flege](#)'s ([1995](#)) model) and whether they can inhibit potential transfers through an awareness-raising multimodal training approach through spectrograms and gestures.

Hence, the following hypotheses are presented:

H1: *L1 French learners of English release utterance-final stops in English at rates that mirror their L1;*

H2: *Homorganic pairs of stops are more likely to exhibit stop-unrelease in the first stop than heterorganic pairs;*

H3: *The combination of tools—i.e., spectrograms to raise awareness and gestures to inhibit bursts in stops—significantly helps the learners to control stop-unrelease in final position and in pairs of stops.*

4. Materials and Methods

4.1. Participants

The participants were L1 French second-year university students majoring in English. The students were in their early 20s. Unfortunately, some students dropped out from university or were absent when the experiment was being conducted and did not complete the experiment. During the first recording session, 42 students started the study and were distributed as evenly as possible between the control and the test group (control: 14 women and 6 men, test: 20 women and 2 men). During the second recording session, the number of students was 31 (control group: n = 17, 11 women, 6 men, test group: n = 14, 12 women,

2 men). During the third recording, there remained 3 women from the control group and 2 women and a man in the test group.

The participants were recorded in 2016 in a sound attenuated room at a sampling frequency of 44,100 Hz. The learners were recorded with Praat (Boersma and Weenink 2022). The microphones used were headset stereo microphones (Plantronics Audio 655 DSP and V7 J151648). The distance between the speakers' mouth and the microphone was controlled for.

While all students read the stimuli with contextualised voiceless stops in English, 17 of them read stimuli with voiceless stops in French in a similar context (prior to reading the English text). Due to timetable constraints, it was more difficult to train students from the test group and ask them to do an extra recording in French, as it would increase the risk of losing more participants during the study[3]. Sixteen students from the control group read the stimuli in both French and English. One student (subject ID: TAI01M) from the test group happened to participate in this recording. His data were nonetheless included. One student from the control group was removed from the study because she accidentally attended the training session, thereby impacting the overall scores of release in the second recording (subject ID: COL28F).

4.2. Recording Phases

Phase 1 (*pre-training*, *first recording*): Both the control and the test group were asked to read sequences of two words and sentences containing voiceless stop-stop sequences straddled between words (homorganic and heterorganic), and word- and sentence-final voiceless stops. Namely, *that **p**an*, *wait for me at that **t**able over there* or *I like that truck* (see Appendix B). Since the availability of the students was limited, stimuli were uttered only once. One week later, during the intervention phase, only the test group watched an explanatory video to raise awareness on stop-unrelease in English. The control group did not watch anything and did not receive any training.

Phase 2 (*post-training*, *second recording*): Then, immediately after training, both the control group and the test group were asked to read the same stimuli a second time.

Phase 3 (*follow-up test*, *third recording*): The control group and the test group were asked to read the same stimuli a third time a month later with no extra training for the test group and no training given to the control group.

The stimuli in French were composed of a similar structure: verb-noun nonce compounds coined with real French words with a simple CVC structure, sentence-final stops and sentence-medial stop-stop sequences (see Appendix A). Word-final stops were omitted by mistake. A summary of the experimental phases can be found in Figure 2.
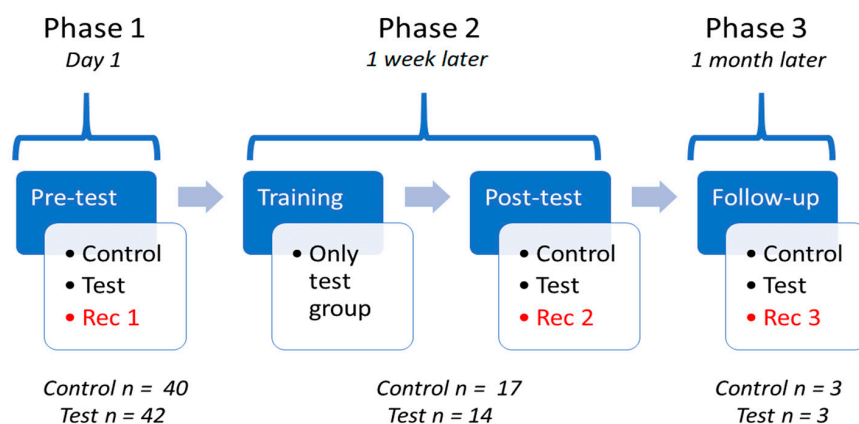

Figure 2. Summary of steps during the experiment.

4.3. Stimuli

The stimuli were compiled by the authors. Due to time constraints, participants were asked to read the stimuli only once. **Straddled between two words**: Stimuli start with

pairs of words. The first word ends with a voiceless stop and the second one starts with the same or another voiceless stop, e.g., *bla**ck** **p**an*. They contain all 9 possible combinations of voiceless stops in that context. **Word-final stops**: Monosyllabic CVC words containing a final stop were also chosen to measure the proportion of release/unrelease in final position (9 words, /p/, /t/ and /k/ appearing in 3 different words, e.g., *a trap*, *a hack*, *a hit*). **Sentence medial stops**: To avoid a potential wordlist effect, simple sentences were also created, e.g., *sto**p** **t**alking and listen to me*. They included a two-word noun phrase with a stop at the end of Word 1 and at the beginning of Word 2. To limit the effect of rare or specific words on stop-unrelease, Word 1 was composed of 4 highly frequent monosyllabic words ending in a stop: *stop*, *that*, *can't* and *like*. **Sentence-final stops**: In total, 23 sentences end in a voiceless stop, e.g., *I've just told Ni**ck***. A set of 5 sentences end in the closing diphthong /aɪ/ + /t/ so as to explore the potential effect of a closing diphthong on t-unrelease (e.g., *I'm going out tonigh**t***). They will not be included in the analyses and Results Section.

4.4. Video Tutorial: Awareness Approach

The awareness-raising training consists of watching a video in which a trained phonetics instructor demonstrates stop-unrelease with gestures. The instructor provides key elements of stop-unrelease before inviting the students to practise along with her.

- In the first part of the video, some research on stop-unrelease in spontaneous speech for American English (Davidson 2011) is summarised.
- In the second part, the articulatory and acoustic characteristics of unrelease are presented with excerpts from an existing video on articulatory phonetics (UBC Visible speech, 2015: https://youtu.be/dfoRdKuPF9I). The video was then stopped, and spectrograms were shown and commented during that session by the same phonetics instructor using the freely available program Praat (Boersma and Weenink 2022).
- The third part of the video explains how to inhibit the release of voiceless stops. The main learning aid is a cutoff gesture found in choir-conducting as illustrated in Figure 3. A circular movement of the wrist with the hand curling into a fist once a full turn is reached. It is sometimes called the *pig-tail* gesture in French[4]. The closed fist coincides with stop-unrelease. In a stop-stop sequence, the release of the second stop is accompanied by the rapid uncurling of the fingers into an open hand. The fingers are projected forward as if following the direction of the airflow coming out of the speaker's mouth. This prepares the learners for the aspiration of the second stop at a later stage.

Figure 3. Example of a cutoff gesture to mime a sequence of two voiceless stops in the sequence *bla**ck** **p**an* (stop 1 = /k/ stop 2 = /p/). The circular movement occurs before stop 1, i.e., during /blæ/ and helps the learner to anticipate stop-unrelease for [k̚], mimed with closed fist. The second stop in *pan* is released as fingers start fanning out.

A potential drawback of creating a video with multiple teaching approaches (visual and kinaesthetic) is that it becomes impossible to single out the *one* factor with the most impact on learners overall. However, we aimed to reach different learning profiles or individual preferences, and to provide students with multiple ways to acquire unreleased stops since "the way students engage in learning is rarely restricted to one single or dominant approach or learning strategy" (Rogiers et al. 2019, p. 386).

4.5. Measurements

Release was treated as a binary variable: released (R) vs. unreleased (U). Auditory and spectrographic analyses were carried out. If the burst was visible on the spectrogram, then the stop was coded as having a release as illustrated in Figure 4. Otherwise, the measured tokens were considered as cases of unrelease (see Henderson and Repp 1982, for more fine-grained metrics with a five-category classification).
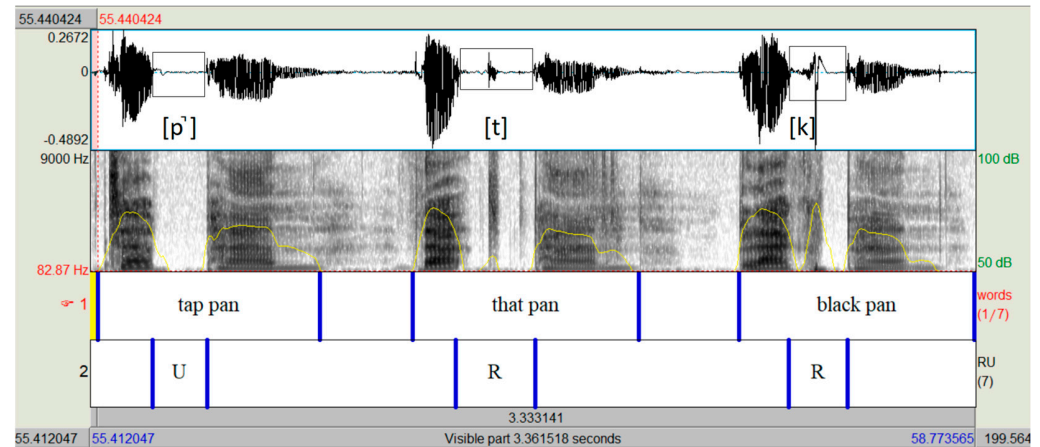

Figure 4. Spectrographic representation of an advanced French learner of English reading *tap pan*, *that pan* and *black pan*. U: unreleased, R: released. Only the first [p˺] of *tap pan* is unreleased (speaker ID: CAN03F, rec1, female speaker).

5. Results

5.1. French Stops

Amongst the 17 L1 French speakers, the overall release rates was 50.4% and the unrelease, 49.6%. However, disparities in scores that were mostly due to stop position. Sentence-final stops were released almost at ceiling (98.1%, see Figure 5). When read in pairs of words, heterorganic pairs were released three times more often than in a sentence (65.7% vs. 18.9%). Homorganic pairs are four times more often released in pairs of words than inside a sentence (42.6% vs. 9.7%).
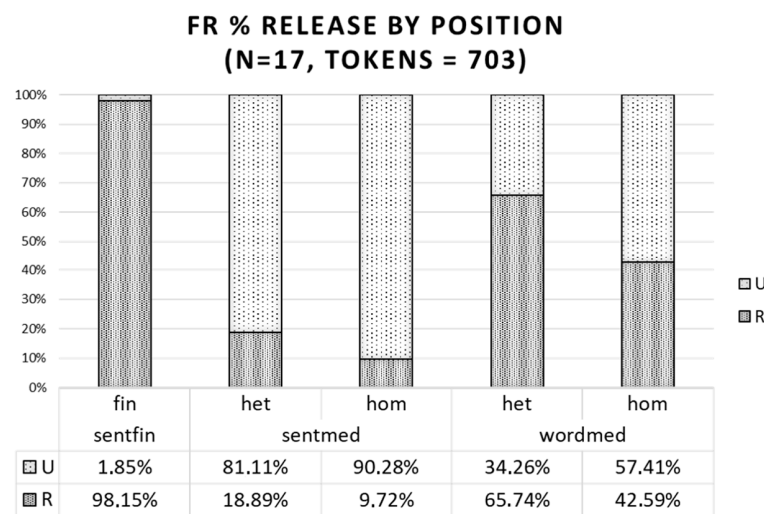

FR % RELEASE BY POSITION (N=17, TOKENS = 703)

	fin	het	hom	het	hom
	sentfin	sentmed		wordmed	
U	1.85%	81.11%	90.28%	34.26%	57.41%
R	98.15%	18.89%	9.72%	65.74%	42.59%

Figure 5. French baseline: proportions of released (R: dark grey) vs. unreleased stops (U: light grey) by task: sentence reading (sent) vs. reading pairs of words (words); and by position: sentence-final (sentfin), before a stop with a different place of articulation (het) or with the same stop (hom). 17 learners (16 from control group and 1 from test group, 703 tokens).

5.2. Release in French vs. English: Phase 1 Only

This section tests whether stop-unrelease differs from one language to the other in the three similar contexts for the 17 students having read both the French and the English stimuli: end of a sentence, pairs of stops inside a sentence and inside a pair of words. Only the first recording in English was retained in this data subset. The results are displayed in Figure 6 in the form of a conditional inference tree. The tree uses chi-square tests with Bonferroni corrections to partition the tree (Hothorn et al. 2006). A mixed-effect model and multiple chi-square tests were also run in RStudio (R Core Team 2023) to confirm the robustness of these results. The higher the variable on a tree, the stronger the effect. Whenever variable levels split, they are deemed to impact scores of release in a significantly different way. The bars below display the aggregate proportions of release/unrelease under each condition. Position (variable wordSent) has a stronger impact on release than language ($X^2(2, N = 2478) = 1665.3$, $p = 2.2 \times 10^{-16}$). Pairs of stops inside a sentence (sentmed) are the least released in both languages—slightly more released in French (14.8%) than in English (9.4%). Although a chi-square test indicated that this was significant enough, $X^2(1, N = 1380) = 7.15$, $p = 0.007$, the statistical power points to a small effect ($\omega = 0.07$ for language vs. 0.73 for position, see Cohen 1992, p. 157 on statistical power thresholds: small effect: 0.10, medium effect: 0.30, stronger effect: 0.50). The results are likely to vary from one cohort to the next but based on this sample of students, we can see that before training, students have comparable allophonic variation patterns in stop-unrelease in both English and French despite minor differences in some contexts. This leads us to conclude the following:

- Sentence-medial position favours stop-unrelease (>80% in both languages, but more so in French);
- Sentence-final position disfavours stop-unrelease (<20% in both languages);
- Pairs of two words such as *tape-porte* or *tap pan* tend to have a release score approximating 50%.
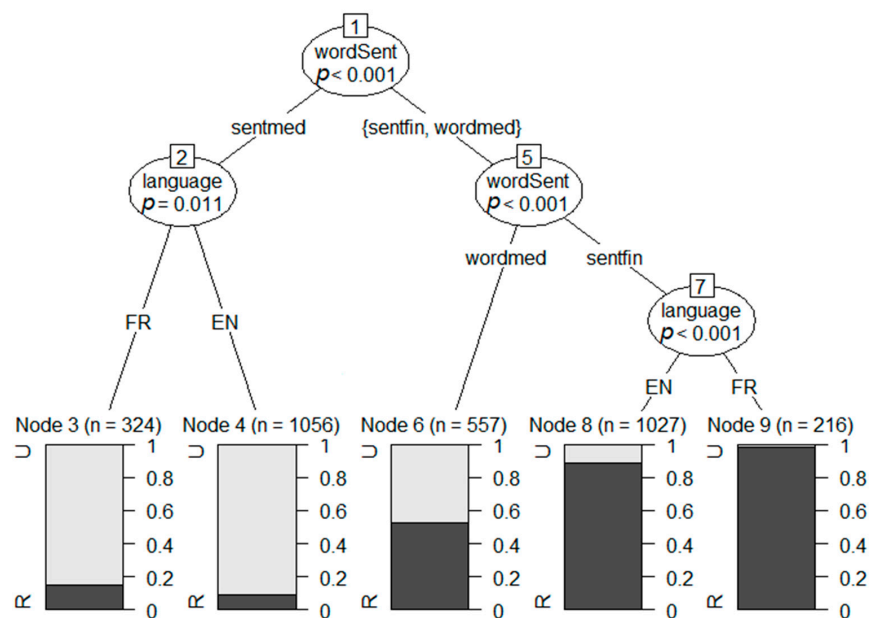

Figure 6. Conditional inference tree by language and position. The higher in the tree, the stronger the effect. Sample of 17 learners including 1 from the test cohort having read both the French and English stimuli (recording in French and first recording in English). Light grey: proportions of unrelease, dark grey: proportions of release.

This highlights the potential impact of the linguistic context and tasks when investigating allophonic variation amongst L1 and L2 speakers in French and English. The next section investigates the effect of training on stop-unrelease across all speakers in English.

5.3. Release in English: Phase 1 vs. Phase 2

We first checked for potential differences in release scores in English between Recording 1 vs. Recording 2 in the control group. With the subject COL28F, the *p*-value for the chi-square test was slightly below the critical value, and without this learner, it rose slightly above it (with COL28F: $X^2(1, N = 2244) = 4.44$, $p = 0.035$, $\omega = 0.045$, without COL28F: $X^2(1, N = 2112) = 3.64$, $p = 0.057$, $\omega = 0.042$). This means that without this learner, the differences in release scores are not significant enough between Recordings 1 and 2 in the control group.

Then, we investigated potential differences in release scores in English between the two cohorts (test vs. control subjects having completed both Phases 1 and 2, the speaker COL28F was excluded from now on). Due to possible individual differences, the overall release rates differed slightly between the two cohorts in the first recording ($X^2(1, N = 1056) = 11.59$, $p = 0.0007$). However, the statistical power ($\omega = 0.07$) points to a minor effect. If we add the nine students who completed Phase 1 only (three in the control group, six in the test group), the differences between the cohorts are ironed out ($p = 0.38$ ($\omega = 0.02$)).

Finally, the effect of training on stop-unrelease amongst the test group was examined (speakers having completed both Phases 1 and 2 only) and was deemed significant ($X^2(1, N = 1842) = 298.52$, $p < 2.2 \times 10^{-16}$, $\omega = 0.404$). The average release rate in the control group was 40.2% (rec1 38.2%, rec2 42.3%), while the scores of unrelease in the test group rose from 45.8% (rec1) to 84.3% after training (rec2). More specifically, sentence-final and word-final stops were overwhelmingly released (90% and above for both cohorts) before training (see Figure 7). Training had a significant impact on sentence-final stop-unrelease in English which rose from 10% to 71.6%, and the difference was slightly smaller in word-final position (from 7.9% to 61.1%). After training, unrelease rose by about 40% in pairs of words (from 49.5% to 91.7%).
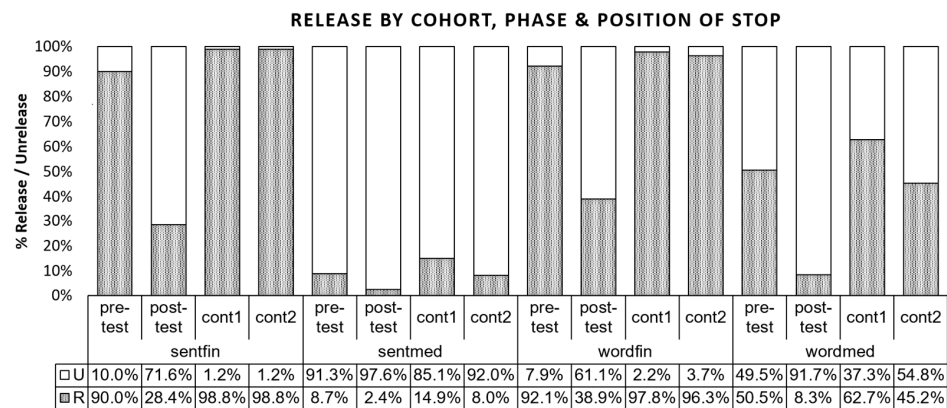
RELEASE BY COHORT, PHASE & POSITION OF STOP

	pre-test	post-test	cont1	cont2	pre-test	post-test	cont1	cont2	pre-test	post-test	cont1	cont2	pre-test	post-test	cont1	cont2
			sentfin				sentmed				wordfin				wordmed	
□ U	10.0%	71.6%	1.2%	1.2%	91.3%	97.6%	85.1%	92.0%	7.9%	61.1%	2.2%	3.7%	49.5%	91.7%	37.3%	54.8%
▨ R	90.0%	28.4%	98.8%	98.8%	8.7%	2.4%	14.9%	8.0%	92.1%	38.9%	97.8%	96.3%	50.5%	8.3%	62.7%	45.2%

Figure 7. L2 English: proportions of release (R)/unrelease (U) by group and task. Sentence-final (sentfin). Cont1: first recording of control group. Cont2: second recording of control group. Tokens: n = 4020, speakers: n = 31.

Figure 8 complements the preceding figure and indicates which conditions have a stronger influence on stop-unrelease. Stops in final position, be they placed at the end of a sentence or a word, are the most affected by training (Node 13), which leads to a tripling of unrelease scores (Node 15 vs. 14). In medial position, scores depend on whether the stops are straddled between two words in isolation or within a sentence (Node 2). Homorganic pairs have higher scores of unrelease than heterorganic pairs (Nodes 4 and 10 vs. Nodes 6, 7 and 11), yet the difference after training is ironed out in pairs of words (wordmed, Node 12).

Figure 9 shows rates of stop-release by linguistic context (sentences vs. pairs of words) in the test group (before and after training). Overall, homorganic pairs of stops were more often unreleased (rec1: 75.9%, rec2: 98.1%) than heterorganic pairs (75.9% vs. 95.5%) or than stops in final position (11% vs. 72.1%). In final position, /k/ had higher scores of release in both pre-test and post-test. In word-medial position, the homorganic pairs with

velar stops were least affected by training despite being three times more often unreleased after training (pre-test: 43% vs. post-test: 14%). The heterorganic pair /kp/ consistently exhibited more release across all conditions in both the pre-test and post-test results. In word-medial position, the bilabial stop /p/ was the least released when followed by the alveolar stop /t/.
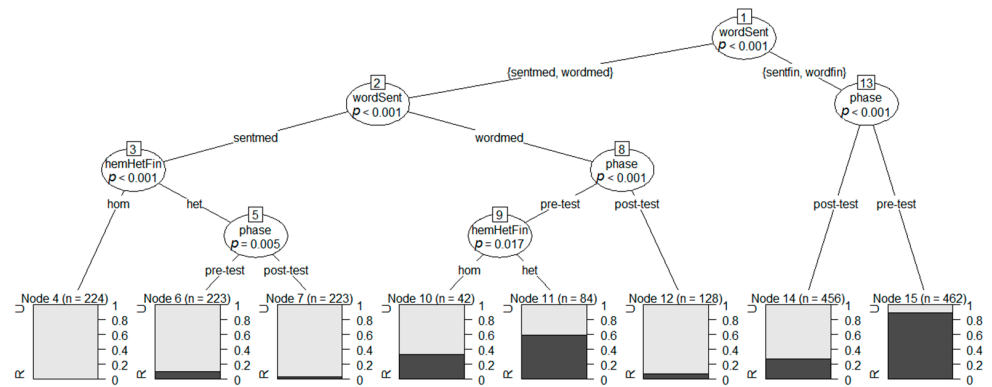

Figure 8. Conditional inference tree. Test group only (Phases 1 and 2). Proportions of release by linguistic context and stop combination: pre-test vs. post-test. het: heterorganic pairs, hom: homorganic pairs. R: release, U: unrelease. Tokens: n = 1842, speakers: n = 14. Dark grey: released. Light grey: unreleased.
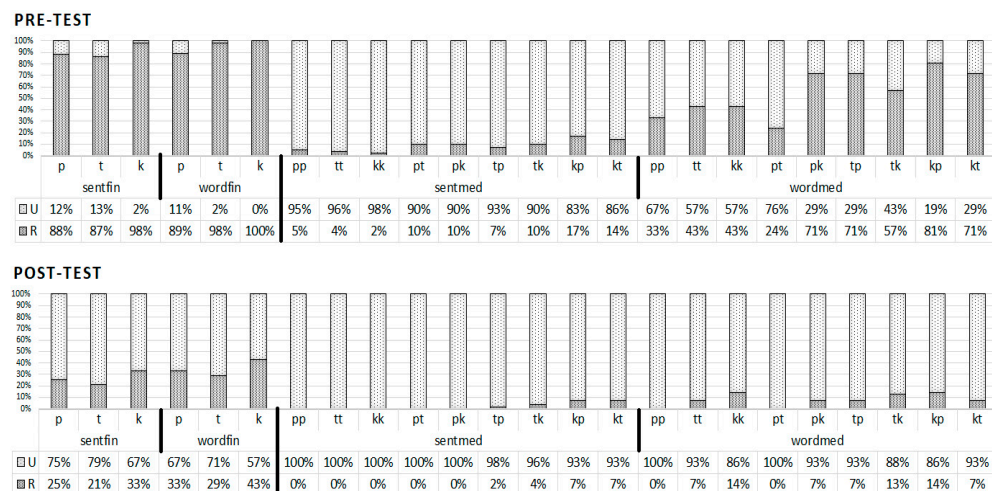

Figure 9. Release by position and stop type and combination: pre-test vs. post-test. Het: heterorganic pairs. Hom: homorganic pairs. pt: percentage of release in /p/ within the pair /pt/.

A logistic mixed effects regression was run to confirm the effect of the training on the proportion of stop-unrelease along with the environment in which the stop is (final/heterorganic pair or homorganic pair). The subjects and the words used as stimuli were included as random effects. The model specifications were as follows: release ∼ stopType + cohort * recording phase + (1 | speaker) + (1 | context). The results point to a significant interaction between the group and the recording sessions ($p < 2 \times 10^{-16}$), with the post-test group having significantly lower rates of release than the control and the pre-test groups. There was also a main effect of position with final stops being significantly more released overall compared to homorganic and heterorganic sequences of stops (for both differences: $p < 2 \times 10^{-16}$). The next section investigates whether the training had a lasting effect on the sample of students who re-read the same stimuli in English after a month without further training on stop-unrelease.

5.4. Release in English: All Three Phases

This section analyses the evolution of stop-unrelease amongst the six learners having completed Phases 1, 2 and 3. Stop combinations were classified into a binary variable (within a pair or in final position), since the differences in release scores rely mainly on this opposition (see Figures 8 and 9 above). In Figure 10, the scores of release amongst speakers having completed all three phases depend on the position (Node 1) of the stop (final position or in pairs of stops) and on whether they received the training (remaining nodes). The pair context did not lead to significant differences in release scores amongst the control group (all three phases) and the test group (pre-training). In the test group, the scores were slightly higher in Phases 2 and 3. This means that during the follow-up reading session, the effect of training was still observable a month later. A similar pattern was found for stops in final position with a more striking difference in scores between speakers having received training and those with no training, even though the *p*-values are considered equivalent ($p = 0.001$). In Phase 3, release decreased in the control group (cont3, Node 5), while within the test group, it increased a month after training (post-test2, Node 8). This means that the effect of training was less durable for stops in final position than it was for pairs, whose scores of unrelease were initially very high (above 80%).
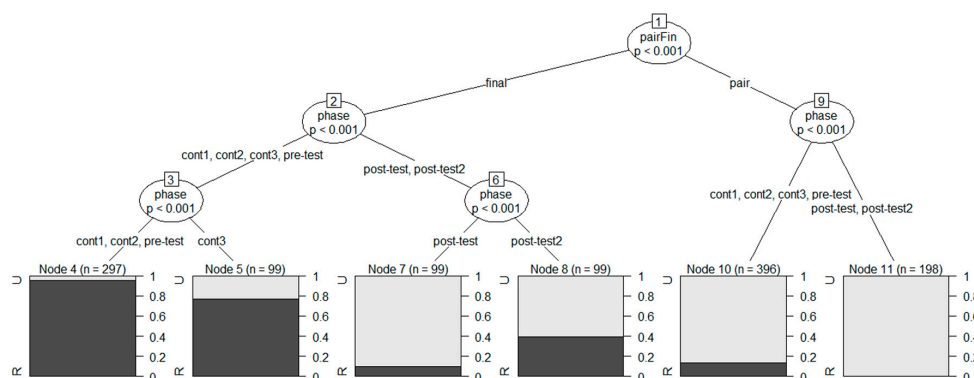

Figure 10. Conditional inference tree. Proportions of release by position (final or in a pair). All 6 learners having completed Phase 3 (test: n = 3, control: n = 3, tokens: n = 1188). R: released. U: unreleased.

Figure 11 exhibits release scores by phase and speaker. Interestingly, in both cohorts, two learners have similar scores and one has scores that differ from the other two learners in Phase 3 in particular (CME22F and TFE06M). CME22F from the control group seems to inhibit release almost like someone who has received training on stop-unrelease. It is not impossible that she may have talked to her peers from the test group and learnt from them. Some form of awareness is noticeable in her third recording. In addition, after double-checking the recordings for TFE06M, we noticed that the effect of training on stop-unrelease in final position did not last as long as it did for the other two learners (TAL02F and TNA26F). While unrelease stood at 48.5% before training, it almost doubled to 88% immediately after training, before dipping to 60.7%. More specifically, in Phase 3, release was exclusively found in word- and sentence-final positions (resp. 66.7% and 83.3%). However, in pairs of voiceless stops, TFE06M controlled the release of stop 1 and started to add aspiration on the second stop during Phase 2 and maintained it in Phase 3 (e.g., *tap pan* realised as [tæp˺pʰæn]). This suggests that it is probably easier to produce a new allophone of a phoneme that is not present in the learner's inventory (aspirated stop) than to acquire a position-dependent allophonic variation pattern that differs between an L1 and an L2.

An inspection of spectrograms of the learners' recordings can also illustrate the progress in more detail. Figure 12 represents *tap pan* read by speaker TNA26F. Stop-release in medial position is visible in Phase 1 (top), then absent in the remaining phases. Word-initial aspiration is visible for *tap* but almost absent for *pan* in Phase 1 (i.e., below the

30/50 millisecond threshold, Cho and Ladefoged 1999). In Phases 2 and 3, aspiration is present in both words.

% RELEASE IN PHASE 1, 2 & 3. SPEAKERS: N = 6, TOKENS: N= 1188

	cont1	cont2	cont3	cont1	cont2	cont3	cont1	cont2	cont3	pre-test	post-test	post-test2	pre-test	post-test	post-test2	pre-test	post-test	post-test2
speaker ID =>	CCH06F			CSA30F			CME22F			TAL02F			TNA26F			TFE06M		
U	53.0%	50.0%	40.9%	42.4%	51.5%	53.0%	33.3%	34.8%	75.8%	48.5%	97.0%	86.4%	40.9%	100.0%	92.4%	48.5%	87.9%	60.6%
R	47.0%	50.0%	59.1%	57.6%	48.5%	47.0%	66.7%	65.2%	24.2%	51.5%	3.0%	13.6%	59.1%	0.0%	7.6%	51.5%	12.1%	39.4%

Figure 11. Proportions of release by phase and speaker (ID ending in F: female speaker, in M: male speaker). All 6 learners completed Phase 3 (test: n = 3, control: n = 3, tokens: n = 1188).

Speaker TNA26F (rec1). Tap pan: first item on the list.

(rec2)

(rec3)

Figure 12. Spectrographic representation of the speaker TNA26F's progress: before training (**top**), immediately after training (**mid**) and a month after training (**bottom**): *tap pan*.

During Phase 1, the speaker TFE06M's stops are generally released (Figure 13, top) in word-final position. In Phase 2 (mid), the second /k/ is released but the other stops are not. In Phase 3 (bottom), both occurences of /k/ are released even though the duration of the burst is visibly shorter than in Phase 1.
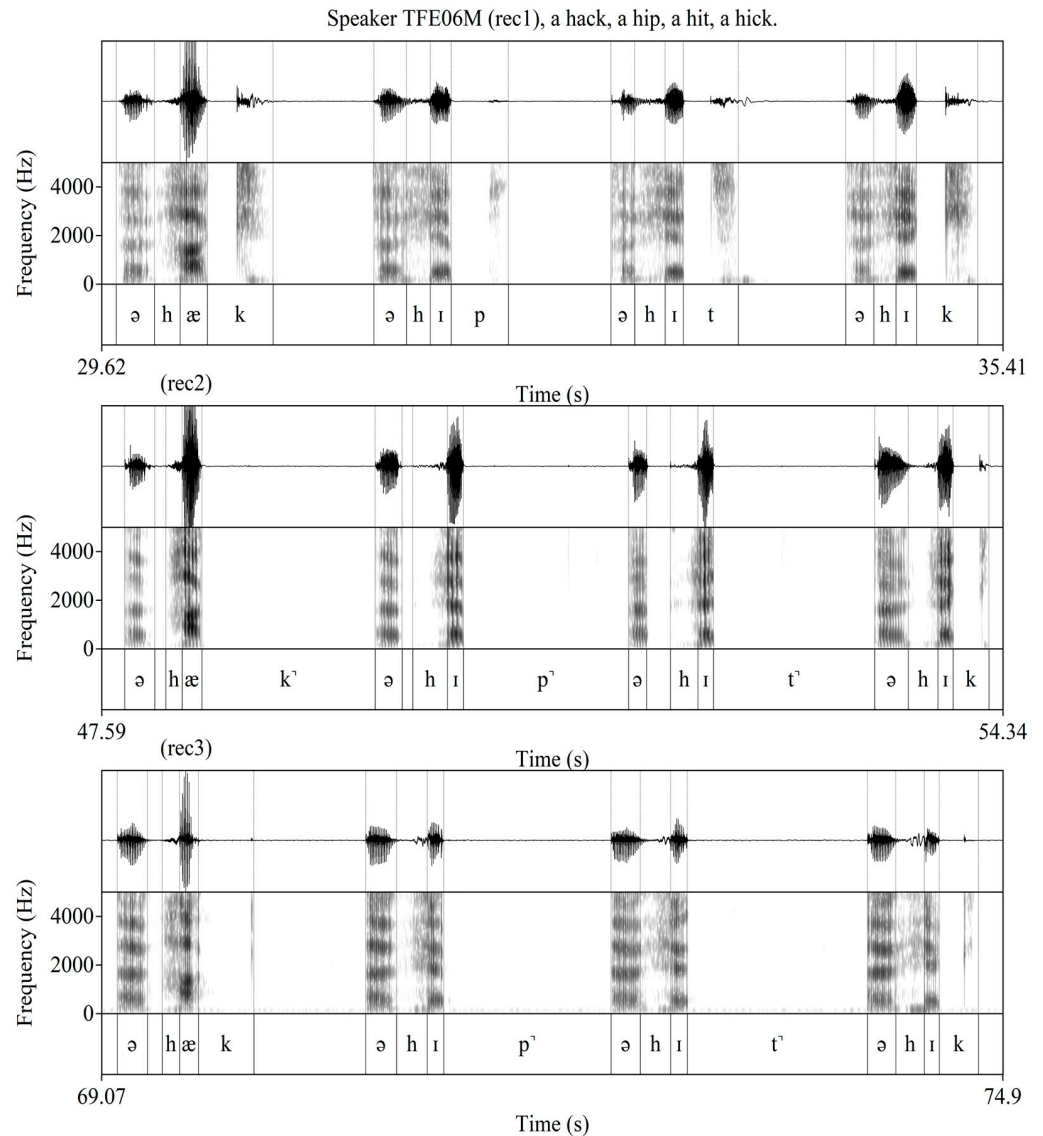

Figure 13. Spectrographic representation of speaker TFE06M's progress: before training (**top**), immediately after training (**mid**) and two months after training (**bottom**): *a hack*, *a hip*, *a hit* and *a hick*.

6. Discussion

Based on Flege's (1995) model, this study assessed whether cross-linguistic transfers occur at a sub-phonemic level, i.e., stop-unrelease, and whether the allophonic variation patterns observed amongst learners of an L2 may stem from patterns found in the learners' L1. It also tested whether a diversified training approach (awareness-raising with spectrograms and gestures) could lead the learners to inhibit cross-linguistic transfers from their L1 and to opt for patterns that approximate those by native speakers of English.

H1: *L1 French learners of English release utterance-final stops in English at rates that mirror their L1.*

Although not all students were assessed on stop-unrelease in French, it is clear that stops in sentence final position are overwhelmingly released (98.1%, based on 17 subjects). Similar results are observed across all participants in English before the training took place (90.9% for all participants having completed Phase 1, based on 39 subjects). In pairs within sentences, the trend is almost the opposite (FR: 14.8%, EN: 9.8%), whereas rates of release approximate chance level in pairs of words in isolation with a tendency to favour release (FR: 58%, EN: 55.3%). These trends point towards an equivalence classification (Flege 1987) at a sub-phonemic level in the sense that learners seem to tap into the allophonic variation patterns in French to produce stops in English and that these patterns depend mostly on the environment they are in (in pairs or in final position) and on the linguistic structure they are in (pairs of words in isolation or in a sentence).

H2: *Homorganic pairs of stops are more likely to exhibit stop-unrelease in the first stop than heterorganic pairs.*

More subtle differences are observed in productions before training. In both languages and linguistic structures, homorganic pairs lead to higher scores of unrelease than heterorganic clusters. This aligns with Rojczyk et al.'s study on Polish accented English: "homorganic clusters in Polish [being] optionally unreleased" (Rojczyk et al. 2013, p. 13), the perception, and subsequently imitation, of such clusters in English (L2) was facilitated despite the absence of any explicit training on stop-unrelease. For stops in word-final position or heterorganic pairs of stops, however, explicit training seems to be needed as intelligibility issues may be at stake (Cruttenden 2001).

H3: *The combination of tools—i.e., spectrograms to raise awareness and gestures to inhibit bursts in stops—significantly helps the learners to control stop-unrelease in final position and in pairs of stops.*

A comparison of the productions in the control group versus the test group clearly shows that our multimodal training had a significant impact on stop-unrelease across all positions and more importantly, in utterance-final position. Although this remains to be tested further with more participants, the follow-up test a month later showed the lasting effects of the training, as proportions of stop-unrelease remained high even in utterance-final position. Even though the rates of unrelease went down slightly, we could say that the results are more realistic than scores found immediately after training as they are closer to rates found in large corpora of spontaneous speech in English (Byrd 1992, 1996 or Davidson 2011). Our findings align with Bergier's study on the positive impact of metalinguistic awareness on second-language pronunciation performance even for a sub-phonemic feature like stop-unrelease (Bergier 2014). During the recording sessions, many students used the *pig-tail* gesture to inhibit release. A future study could involve filming students while producing unreleased stops after having received similar training and interviewing them on the strategies they used to inhibit release. Aspiration could also be taken into account while measuring progress, as Amand and Touhami's (2016) study indicates that young learners of English seem to acquire aspiration more easily than stop-unrelease. It is possible that advanced learners of English have the ability acquire both sub-phonemic details at the same time, i.e., stop-unrelease in Stop 1 and aspiration in Stop 2. Finally, the alveolar /t/ having an extra allophone [ʔ] (see Byrd 1992, p. 29), they should be investigated further with articulatory measurements of students' productions since advanced French learners of English are more sensitive to glottal stops than aspiration in perception (Shoemaker 2014).

7. Conclusions

In France, no explicit training on stop-unrelease is found in English pronunciation textbooks nor in university syllabi for English majors since it is probably considered as a non-contrastive phonetic feature in English. However, as Schwartz et al. (2014)

remark, "success in acquisition is predicted on the basis of sub-phonemic phonetic detail", including allophonic variation patterns involving stop-unrelease. This paper suggests that Flege's *equivalence classification* of phonemes between an L1 and an L2 also may involve sub-phonemic features like stop-unrelease in pairs of stops and in final position, yet the allophones of these stops can be re-classified after an explicit training involving awareness-raising with spectrograms and gestures. French learners of English initially transferred the allophonic variation pattern of stops from their L1 to their L2. After training, the test group managed to inhibit release even in utterance-final position in their L2, where proportions of release was initially higher than 90%. A month later, students who completed the experiment until the very end produced allophonic variation patterns in stops that were closer to patterns produced by native speakers of English than by French speakers. This awareness-raising approach may also lead to a better perception of stop-unrelease in natural speech in English, thereby leading to a better understanding of seemingly easy segments like "together we can beat cancer" which can be confused with "together we can't be cancer"[5]. More generally, this cross-language speech production investigation provides a window on French native speaker's allophonic variation patterns of stops in French and on their ability to adjust the patterns when speaking English as a second language.

Appendix A. French Stimuli

Pairs of words: un tape-porte, un matte-porte, un braque-porte, un tape-table, un matte-table, un braque-table, un tape-coude, un matte-coude, un braque-coude.

Sentence-final stops: J'ai un problème à la ratte. Cette fois, faut pas qu'il rate. Elle est toute petite. Elle est toute coquette. J'aime pas le rap. Le chat lape. Fume ta pipe. Je regarde un clip. J'ai un Mac©. J'ai un sac à dos East pack®. Je parle à Nick. C'est là que tu cliques.

Sentence-medial stops: Attends-moi à la petite table là-bas, d'accord ? C'est quoi cette petite trace ! C'est une petite pelle, rien d'autre ! J'ai craqué sur cette petite Polonaise ! J'aime pas cette petite cuisine ! Cette petite cage n'est pas assez grande pour l'oiseau ! Il attrape Paul par la manche ! N'attrape pas froid ! N'attrapes-tu pas froid en hiver ? N'attrape-t-on pas un coup de soleil ? Il attrape Karen par la manche. Il attrape constamment froid. Il plaque Karen sans raison. J'aime le MacCafé®. C'est une vraie plaque tournante ! J'aime l'acteur MacTurner. C'est une plaque pour accueillir les déchets. Elle plaque Paul sans raison.

Appendix B. English Stimuli

Pairs of words: Tap Pan. That Pan. Black Pan. Tap Tap. That Tap. Black Tap. Lap Cat. That Cat. Black Cat. A Trap. A Mat. A Hack. A Hip. A Hit. A Hick. A Sap. A Sat. A Sack.

Sentence-final stops: I went to the cinema last night. I'm going out tonight. Yes, yes, all right. I need to make things right. Do you wanna fight? Are you really gonna fight? Look at the rat! That's where he sat. Please take a seat. That's where we met. I don't like rap. I bought a map. I want a sip. I made a clip. I have a Mac©. I have to pack. I've just told Nick. That guy's a dick. I've never done it. I've never said that. That's what they lack. Tell him to stop. That's a mop. Time to pack.

Sentence-medial stops: Wait for me at that table over there, will you? That tent's beautiful! I liked that pun! I love that park, it's one of my favourites. That customer drives me mad! That cookie's raw! Stop paying with your card, please! Stop pushing the car! Just stop talking, will you? Stop telling me what to do. Stop cooking and listen to me. Stop caring about other people so much. I like cakes that aren't too moist. I like cooking after work. I like talking to you! I like tea pots. Do you like parties? I quite like poker. You can't talk to me like that! You can't turn around. Sorry sir, you can't park your car here. You can't put the blame on me. Excuse me, you can't cook in here. Sorry Miss, but you can't come in here.

Notes

1. Molholt (1988) also provides an interesting list of techniques to help Chinese learners of English to improve their pronunciation of English (at both segmental and suprasegmental levels) through the use of spectrograms.
2. For a brief description of the TIMIT database, see UCLA's Working Papers in Phonetics vol. 81, 1992, p. 1 ff. https://escholarship.org/content/qt53g8c5mg/qt53g8c5mg.pdf#page=5 (accessed on 30 June 2024).
3. The recordings of the 17 French participants also served as a post-hoc baseline for Amand and Touhami's (2016) preliminary study.
4. In French: *queue de cochon*. https://www.pedagogie.ac-nice.fr/dsden06/eac/wp-content/uploads/sites/5/2019/01/Chant_choral___Les_gestes_du_chef_de_choeur.pdf (accessed on 30 June 2024).
5. This type of misunderstanding was observed amongst advanced learners of English majoring in Applied Languages. They do not have any pronunciation classes. The task was to transcribe the voiceover demo in orthographic spelling before reading the script aloud ("Commercial Demo" section, speaker Sahar Deshmukh (from 00:59 to 01:03): https://theshowreel.com/portfolio-items/demo-examples/, accessed 17 April 2024).

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