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A corpus-based study of the distribution of word-final schwa in Standard French and what it teaches us about its phonological status

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Abstract

What is commonly considered as an epenthetic vowel can actually refer to at least two different realities: phonological epenthesis or phonetic excrescence. French schwa, noted [ə], is a vowel alternating with zero and limited to unstressed syllables that can appear word-internally or word-finally. This paper presents an extensive description of the distribution of word-final schwa in Standard French in order to shed light on its nature: is it an intrusive vowel or a full epenthetic vowel? To that extent, three large corpora of French containing more than 110 hours of speech were used to establish the presence of word-final schwa as a function of sociolinguistics, orthography, phonotactics and phonetics. Our conclusions are that word-final schwa is impacted by speech style, gender,

orthography, phonotactics (i.e., the number of adjacent consonants and their sonority profile), and the phonological properties of the codas. However, speech rate does not impact word-final schwa realization. The specific results lead us to suggest that word-final schwa in Standard French shares similarities with intrusive vowels but ultimately behaves like a legit epenthetic vowel.

Keywords: schwa; epenthesis; pronunciation variation; Standard French; large corpora; automatic alignment

1. Introduction

What is commonly considered as an epenthetic vowel can actually refer to at least two different realities: phonological epenthesis or phonetic excrescence. Epenthetic vowels indeed vary so much across languages that they may not all rely on the same mechanisms. They are often a schwa-like vowel with few or no phonological specification, i.e. a centroid vowel, typically quite short, prone to co-articulation and sometimes not very different to the mere audible release of a consonantal constriction (Silverman 2011). This last characteristic has brought some researchers to posit a particular kind of schwa, called “excrescent” (Levin 1987) or “intrusive” (Hall 2006), that plays an important functional role by providing acoustic cues to the preceding consonant but differs from a full-fledged epenthesis in that it remains essentially a phonetic object with no phonological implications. Thus, Hall (2006) proposes that an intrusive schwa would generally occur in heterorganic clusters, is likely to be optional, disappears at fast speech rates, and does not seem to have the function of repairing illicit structures. On the other hand, full epenthetic schwas would not be dependent on speech rate and have the function of repairing structures that are marked, in the sense of being cross-linguistically rare.

One segment in particular, given the variety of its realizations and of the proposed representations in phonological frameworks, raises the question of its epenthetic vs excrescent status: Standard French word-final schwa. French schwa, noted [ə], is traditionally referred to as a vowel that alternates with zero and is restricted to unstressed syllables (except in some function words such as *je*, ‘I’ or *que*, ‘that’, that can be stressed, or enclitic *le*, ‘him/it’, that is never elided, and therefore will not be considered in the present study). It can surface word-internally in first syllables as in words like [səmən], *semaine*, ‘week’, word-internally as in words like [ʁapətise], *rapetisser*, ‘belittle’, or word-finally as in words like [katʁə], *quatre*, ‘four’. However, for one point at least there is consensus: French schwa is considered by most researchers as a lexical deletable vowel when word-internal, but as an epenthetic segment when word-final (Tranel 1981, Eychenne 2019, Hutin et al. 2020 among others). We will not challenge this traditional opposition here and assume in the following that word-final schwa in Standard French really is a non-lexical vowel. However, is this word-final schwa in Standard French a full epenthetic vowel, interacting with other segments on the phonological level, or a mere phonetic, excrescent vowel? To answer this question, we will build on Hall’s definition to argue that word-final schwa shares some distributional characteristics with intrusive vowels but ultimately functions as a full epenthetic vowel. Answering this question could provide valuable insights not only for French linguistics, but also for other descriptions of the world’s languages.

This study has two main goals. First, it aims at describing extensively the realization patterns of word-final schwa after all obstruents of French, i.e. /p, t, k, f, s, ʃ, b, d, g, v, z, ʒ/, in three large corpora of French (ESTER, ETAPE and NCCFr) each representing a different speech style. Such an extensive investigation should allow us to establish the sociolinguistic, graphemic and phonological/phonotactic factors that favor or disfavor schwa realization word-finally. Second, we use the results to assess whether schwa behaves more like an intrusive or an epenthetic vowel, which will provide evidence that word-final schwa in Standard French shares similarities with intrusive vowels but actually behaves like a legit epenthetic vowel.

The remainder of this paper is organized as follows. In Section 2, we describe the relevant previous literature on schwa to highlight the factors we chose to investigate. In Section 3, we describe the three corpora selected for the study along with the methodology used to harness the data. Section 4 presents an overview of the sociolinguistic, graphemic and phonological factors associated with the realization of word-final schwa in Standard French. Sections 5 and 6 complete the analysis with the observation of two extra factors: the sonority sequence surrounding schwa-site and speech rate. Section 7 is dedicated to summarizing and discussing the results.

2. French Schwa

2.1. Methodological constraints on previous studies on word-final schwa in Standard French

Since Mende (1880) and Grammont (1894), the patterns for French schwa's word-internal realization or non-realization have been extensively studied (Durand and Eychenne 2004, Ranson and Passarello 2012, Eychenne 2019 for Southern French; Martinon 1913, Leray 1930, Malécot 1955, 1976, Fouché 1956, Delattre 1966, Martinet 1969, Dell 1970, Anderson 1982, Picard 1991, Côté 2000, Ayres-Bennett & Carruthers 2001, Racine and Grosjean 2002, Bürki et al. 2007, 2011, Wu et al. 2016, 2017 among many others). However, less has been said about its distribution in word-final position. Concerning word-final schwa exclusively, most studies have only investigated a specific left or right context. Milne (2014) has limited his studies on word-final schwa after complex clusters, as in Fr. *porte*, 'door', and Dell (1976) and Brand and Ernestus (2018) more specifically to schwa after final obstruent-liquid clusters, such as in Fr. *ministre*, 'minister'. Fónagy (1989), Hansen (1997) and Hansen and Mosegaard-Hansen (2002) restricted their studies to "prepausal" schwa, i.e. a sociolinguistic schwa-tagging realized at the end of a prosodic phrase in Parisian French. The reason behind this imbalance lies in the fact that studies of schwa are necessarily limited by the data. The initial ones mostly relied on grammaticality judgments by one or few informants (very often the authors themselves) on whether schwa could be realized or omitted. As a consequence, these studies are essentially limited to lexical schwas, for which the judgment is straightforward. For example, native speakers of French know that they can pronounce *pelouse*, 'lawn' either as [pəluʒ] or [pluʒ] but not *blouse*, 'blouse' as *[bəluz]. Later on, the studies were based on small corpora, which did not allow extended detailed studies.

As many variational phenomena in continuous speech, word-final schwa appears to be difficult to capture in laboratory data. For such phenomena, only an in-depth investigation of a sufficient amount of tokens from more natural data might

provide a statistically reliable picture. Moreover, since the (non-)realization of schwa is a multifactorial phenomenon, large corpora are necessary to investigate a large set of factors. Over the last decade, the access to increasingly larger corpora processed with the help of digital tools, has led to new ways to investigate old questions, in particular the ones about linguistic variation (Adda-Decker 2007, Liberman et al. 2011, Coleman et al. 2016). It therefore seems to be an adequate framework to investigate word-final schwa, as we now have access to large corpora including numerous tokens across different speech styles and various speakers. Such an approach, enabled by large corpora and automatic alignment, has proven useful to analyze word-internal schwa (Bürki et al. 2007, Wu et al. 2016, 2017), word-final schwa after complex (Milne 2014) or obstruent-liquid coda clusters (Brand and Ernestus 2018) and schwa realization in non-standard varieties of French (Durand and Eychenne 2004, Ranson and Passarello 2012, Eychenne 2019). Several large-corpus based studies have already taken advantage of such technological advances and investigated word-final schwa after all kinds of codas in Standard French (Adda-Decker et al. 1999, 2002; Nemoto et al. 2010; Purse 2019). Their results will be presented in the next section, but it is worth noting already that the most challenging fact for our study has been established by Adda-Decker et al. (2002), who used a corpus of 31 hours of radio interviews in French to investigate the variation between the number of syllables in the canonical ‘full’ form of a word and the number of syllables in the actual spoken form of that same word. They showed that the optional schwa vowel contributes to a large amount of pronunciation variation and that a substantial number of word-final syllables may be completely deleted. Schwa-site, i.e. the place in the speech flow where schwa could be realized, is thus a highly problematic sticking point, showing how much variable French schwa is and justifying the necessity to understand schwa’s status.

The present study builds on such attempts to formalize word-final schwa in Standard French and on the method involving large-scale corpora and automatic processing. Our objective is to provide a general overview of word-final schwa, relying on actual linguistic usage, and including the role of sociolinguistic, orthographic and phonological factors. In order to achieve this goal, we enlarge the scope of the investigation using substantial data (more than 110 hours of speech, i.e. more than 120,000 tokens of word-final obstruents).

2.2. Literature: Factors favoring or disfavoring word-final schwa

Previous literature on the topic has shown that schwa, be it word-internal or word-final, in Standard or non-Standard French, is sensitive to a large array of linguistic and extra-linguistic factors. It will be useful to investigate them to determine whether French final schwa is an excrescent vowel, susceptible to be optional and thus showing different realization rates across linguistic groups and speaking situations and disappearing at fast speech rates, or an epenthetic vowel, that is steadier in the language and across speech rates, and occurs primarily to repair illicit structures.

2.2.1. Sociolinguistic factors

Previous literature has shown that the rate of schwa realization is affected by sociolinguistic factors. Large variation across speech styles and genders, independent of orthography, might mean that final schwa is highly optional and thus might be an

excrecent vowel, while steady rates across speech styles and genders and correlation with orthography would mean that schwa plays a role on the phonological level.

Regarding speech style, Adda-Decker et al. (1999) used the BREF corpus (Lamel et al., 1991), containing 120 hours of read newspaper, and part of the MASK corpus (Lamel et al., 1995), comprised of 35 hours of spontaneous speech, and found that in read speech, final schwa is produced twice as often as in spontaneous speech, where the majority of schwa-sites are realized without schwas. Wu et al. (2016, 2017) used the same large corpora as we do here and showed that more careful speech such as journalistic monologue (ESTER) is generally realized with more first-syllable schwas than casual speech (NCCFr). In the present study, we intend to investigate whether speech style (formal and prepared, possibly read vs formal and non-prepared vs casual and non-prepared) influence word-final schwa like it does word-internal, thus going a little further than Adda-Decker et al. (1999). Milne (2014) used forced-aligned corpora of spoken French (political speeches from AssNat and natural speech from a subset of PFC) to analyze 28,095 word-final consonant clusters, which can be either followed by schwa, as in *quatr[ə] sous*, ‘four coins’, or simplified as in *quat[] sous*, and found, among others, an effect of speech style.

Gender has been far less studied. Only Wu et al. (2017) found that male speakers produce significantly fewer first-syllable schwas than female ones in ESTER and ETAPE, i.e. in formal journalistic speech, be it prepared or non-prepared. However, Purse (2019) investigated two corpora of journalistic speech (ETAPE and BREF80) from which 2,667 tokens were extracted for analysis, and failed to find any difference for word-final schwa. This shows that word-internal and word-final schwas have been reported to react differently to this factor. However, Purse’s study focuses on a limited number of tokens, which does not allow a systematic comparison. Will our study confirm Purse’s results that rates of word-final schwa do not differ between male and female speech, or on the contrary show that word-final schwa behaves like its word-internal counterpart?

The effect of orthography has also been investigated. In French, a word like [sœl], ‘alone’ can be written either <seul> (masculine) or <seule> (feminine). In Standard and Northern varieties of French, the graphic <e> sometimes allows to distinguish between genders but the two words are homophones, while in Southern varieties of French, the two are still phonetically (and phonologically) different. For example, Durand and Eychenne (2004) found a correlation between orthography and schwa realization, but mostly in the conservative Aude-region variety of French (86.8% vs 2.5% of schwa realizations in words respectively ending or not ending in <e>) – a discrepancy that, to them, mirrors the existence of an underlying final schwa and, most importantly, is being lost in more standard varieties such as the Basque-country and Vendée-region varieties of French¹. However, Dell (1985) proposes that the orthography of French words is reliable to reconstruct the presence or absence of schwa in the phonological representation, and Purse (2019) proposes that the realization of word-final schwa in Standard French is partly linked to orthographic representations even in Standard French. Based on the ETAPE and BREF80 corpora, he finds that word-final schwa is realized more than twice as often in words ending in

¹ “Conservative” here refers to the Southern distinction between /Cə#/ and /C#/: According to Durand & Eychenne (2004), the Basque-country variety is switching to the Northern system (and Vendée French is already standard) in that regard, but only in that regard.

a graphic <e>. In his data, words ending in <e> surface with a word-final schwa 18% of the time, compared to 7% of the time in words without an <e>. Will our results confirm Purse's findings, thus suggesting that word-final schwa at least partly relies on phono-graphic representations? If so, this will mean that word-final schwa has to be considered by phonology, at least in part. Indeed, it was shown several decades ago that phonological awareness is impacted by literacy (Seidenberg and Tanenhaus 1979, Taft and Hambly 1985, Ziegler and Ferrand 1998 among many others). More recently, it was shown that the phonological representation of a word or even of a non-word is impacted by the way the word is written, even in times when only the acoustic form is manipulated: In a study of graphic 'mute' <e> in word-final position in particular, Ventura et al. (2001) show that literate native speakers of Portuguese handle differently a /CVC/ sequence spelled <CVC> vs <CVCe>, thus demonstrating an "influence of orthographic knowledge in the representation of spoken language" (p. 413). Following the idea that epenthetic vowels result from a phonological repair while excrescent vowels result from phonetic insertion (Hall 2006), we propose that if schwa realization in French is correlated with orthography, as the results on Portuguese would suggest, it thus has a status in the phonology of native speakers who would realize it as a way to repair an incomplete form.

2.2.2. *Phonetic and phonological factors*

Regarding phonetic and phonological factors, the realization of schwa is classically linked to Grammont's Three Consonants Rule (*Loi des trois consonnes*), that is, to the avoidance of three consonants in a row (Grammont 1894, Delattre 1966, Bürki et al. 2011, Wu et al. 2017). Bürki et al. (2011) and Wu et al. (2017) have shown that this so-called Three Consonants Rule indeed is a factor in the realization of internal schwa in large corpora. This was indirectly confirmed on word-final schwa by Brand and Ernestus (2018) who showed that schwa realization after final obstruent-liquid clusters is linked to the realization of the liquid (both liquid and schwa being realized or not as a binary, categorical process as opposed to the deletion of the obstruent that is rather gradual), and by Milne (2014), who showed that complex clusters are more susceptible to be followed by schwa when the following segment is another consonant.

However, the (non-)realization of schwa has also been argued to depend on the quality of the word-final consonant (Hansen & Mosegaard-Hansen 2002) and on that of the first segment of the following word (Dell 1970, Côté 2000). In particular, Hansen and Mosegaard-Hansen (2002) investigated a specific kind of schwa called "e parasite" ("parasite e") that can surface in phrase-final position in Parisian French. Even though this schwa is a stylistic tagging that remains essentially distinct from word-final schwa in Standard French, the authors find that it surfaces more frequently after clusters than after simplex consonants and more after voiced than after voiceless codas. How do our schwa realizations behave in this regard? These factors, specifically those linked to the consonant preceding schwa-site, are pivotal in our study: The literature has traditionally proposed that the laryngeal feature in particular is not a predictor of epenthesis (Steriade 2001, Lombardi 2001) while all factors are widely acknowledged as favoring audible, possibly voiced consonantal releases that can be perceived as an (excrescent) vowel (Householder 1956, Halle et al. 1957, Malécot 1958, Wang 1959).

Schwa has also been shown to depend on the sonority profile in the C#C sequence (Grammont 1894, Dell 1970, Morin 1978, Côté 2000, Bürki et al. 2011,

Brand and Ernestus 2018, Eychenne 2019). The literature on word-internal (and word-final) schwa suggests that schwas are more likely to drop if the cluster resulting from its absence obeys the Sonority Sequencing Principle (SSP; Bürki et al. 2011). In our case, this corresponds to the first consonant having a higher degree of constriction than the second one (e.g., /pf/, Malécot 1976) or being less sonorous than the second one (e.g., /pl/, Côté 2000: 112-119). The SSP relies on a Sonority Hierarchy, which ranks speech sounds with respect to syllable well-formedness. Although the details are debated, a widely accepted outline for the Sonority Hierarchy is the following (Parker 2011):

[-sonorous] obstruents < nasals < liquids < glides < vowels [+sonorous]

This tolerance for clusters obeying the SSP applies in particular to word-final sequences of consonants, i.e. CC(ə)# (Dell 1976, Brand & Ernestus 2018, Eychenne 2019) and to CCC sequences where the presence of an internal or final liquid (CLC or CCL) reduces the rate of schwa realizations (Delattre 1951). Note however that in these cases, the schwa-site is located after the consonant sequence, not inside it. Concerning the consonants surrounding word-final schwa-site (not just preceding it), another, related phenomenon should also be tested: the Sonority Distance.

The Sonority Distance is a metric used to establish how much two segments are similar in terms of constriction or laryngeal feature, for instance /t/ is closer to /s/, which differs only in constriction, than to /z/, which differs in both constriction and voicing. Languages tend to avoid a sequence of two segments that are too similar: This general avoidance of adjacent similar segments is referred to as the Obligatory Contour Principle (OCP, Leben 1973). The OCP stems from a basic principle in human perception: contrast. It is a restriction on cooccurrence, for instance a phonetic sequence [m:] will be analyzed as a single geminate rather than as two adjacent /m/ phonemes. The OCP can apply to a number of phonological objects (tones, features, phonemes...), vary from language to language and, most importantly, be gradient: In a given language, forms that violate an OCP constraint to a smaller degree will be more frequent than forms that do so to a greater degree (McCarthy 1988). One of the possible strategies to avoid two adjacent identical or similar segments, for instance following morpheme or word concatenation, consists in inserting another, epenthetic segment, thus repairing the illicit sequence (e.g., [məm]). Our hypothesis is thus that, if French has an OCP-constraint against adjacent segments that are close in constriction or laryngeal feature, then word-final schwa in French would be realized more often in such sequences, which would mean that it is used as a repair strategy against a marked sequence, and thus qualifies as an epenthetic segment.

Finally, it is argued that speech rate could be a predictor for schwa (Grammont 1914, Malécot 1976). A higher speech rate is indeed associated with a higher proportion of non-schwa variants, as it was shown for word-internal schwa (Bürki et al. 2011) as well as word-final after complex codas (Hansen 1994, Milne 2014). Speech rate is also one of the factors allowing an epenthetic vowel to be distinguished from an excrescent vowel. It will thus be interesting to investigate this factor to answer our second research question.

3. Data and methodology

Word-final schwa has been described over the years in various linguistic studies as a multifactorial phenomenon. As was pointed out earlier, such fine-grained multifactorial phonetic phenomena are best investigated with a sufficient amount of tokens from natural data so as to provide a statistically reliable picture. In line with Coleman et al. (2016), we built a database of words displaying word-final schwa realization allowing the investigation of the factors favoring or disfavoring its occurrence.

The present study focuses on word-final schwa in three large, manually orthographically transcribed corpora of French, each reflecting a different speech style: formal and prepared, formal and non-prepared, and casual.

The first corpus *Évaluation des Systèmes de Transcription enrichie d'Émissions Radiophoniques*, henceforth ESTER (Galliano et al. 2005), originally contains 80 hours of semi-prepared or prepared speech (radio broadcast news) that we filtered to clear out the data from non-metropolitan French (by excluding the data from international RFI and Moroccan RTM) and keep only Standard French data. The two-part corpus *Évaluation en Traitement Automatique de la Parole*, henceforth ETAPE 1 and 2 (Gravier et al. 2012), contains 13.5 hours of radio data and 29 hours of TV data in French, including debates and interviews. Finally, the *Nijmegen Corpus of Casual French*, henceforth NCCFr (Torreira et al. 2010), is comprised of 31 hours of face-to-face interactions between friends. These corpora allow us to investigate the realization of word-final schwa in an extensive, realistic manner over more than 110 hours of speech.

In this study, Standard French is defined as a widely used variety of French, associated with sociolinguistic prestige and relying mostly on political attachment (Lodge 1993). As such, it does not display local, regional specificities, and is the preferred variety for national media. Thus, using data broadcasted on national TV or radio channels (for ESTER and ETAPE) or selecting native speakers from the Northern half of France for recording (NCCFr), allowed us to limit variation (especially regional variation) in the corpora.

Over 110 hours of data is impossible to label by hand. This study therefore builds on the method described in Hallé and Adda-Decker (2007, 2011). The corpora used in this work contain speech data and their orthographic transcription by native speakers of French, at more or less the sentence level (as sentences in spoken data can be difficult to define). The audio was partitioned into segments of speech on the basis of homogenous acoustic characteristics optimized for word-recognition (Gauvain et al. 1998)², for instance into hypothesized speaker turns. After the transcription and partitioning phases, the orthographic transcripts are aligned with the partitioned segments by an automatic speech recognition (ASR) system which had been developed with the aim of transcribing broadcast data (Gauvain et al. 2002, Gauvain et al. 2005): The system relies (i) on a pronunciation dictionary comprising a series of possible pronunciations for each word and (ii) on acoustic phone models for each phoneme of the French inventory. The alignment phase aims at matching the audio to the manually transcribed words by automatically choosing the best matching pronunciation. This

² The manual time codes were used when available, but much of the training data was transcribed using the automatic segmentation into speaker turns as a unit.

allows to know which pronunciation variant of a word (provided it is available in the dictionary) was realized according to the system, and to have access to the segmentation and labeling of the speech signal at both word and phone levels.

In the present paper, the ASR system was used on forced alignment mode in which variants with and without schwa are possible. For example, the word *mode*, ‘fashion’, in the audio could be aligned with the pronunciation variants [mɔd] or [mɔdə] depending on whether the system judged that the alveolar stop was followed by a schwa or not. This goes for non-orthographical schwa as well, for instance the word *bob*, ‘bob’ could be transcribed either [bɔb] or [bɔbə]. Forced alignment thus behaves like a human listener who would perceive segments in a categorical manner (either schwa is perceived or it is not) based on its knowledge of the language at hand, but unlike a human listener, forced alignment is not “polluted” by lexical access, and is therefore somewhat more reliable.

We investigate schwa realization after all voiceless and voiced obstruents of French, i.e. /p, t, k, f, s, ʃ, b, d, g, v, z, ʒ/, independently of the phone preceding the consonant. The laryngeal feature being one of the acoustic parameters observed, we did not include /ʁ/ nor any nasal or liquid consonant. Indeed, these consonants do not display a phonological voice-voiceless alternation but regularly assimilate with surrounding consonants (Duez 2003) and could therefore have blurred the results. The presence or absence of word-final schwa is examined as a function of sociolinguistic, graphemic and phonotactic factors. The selection excludes all phones standing for a liaison consonant: For instance, /z/ was taken into account if it was the last consonant of the feminine /øʁøz/ *heureuse*, ‘happy, fem.’, but not if it was the liaison consonant realized after the masculine form of /øʁø/ *heureux*, ‘happy, masc.’, as in /øʁøzami/ *heureux ami*, ‘happy friend’.

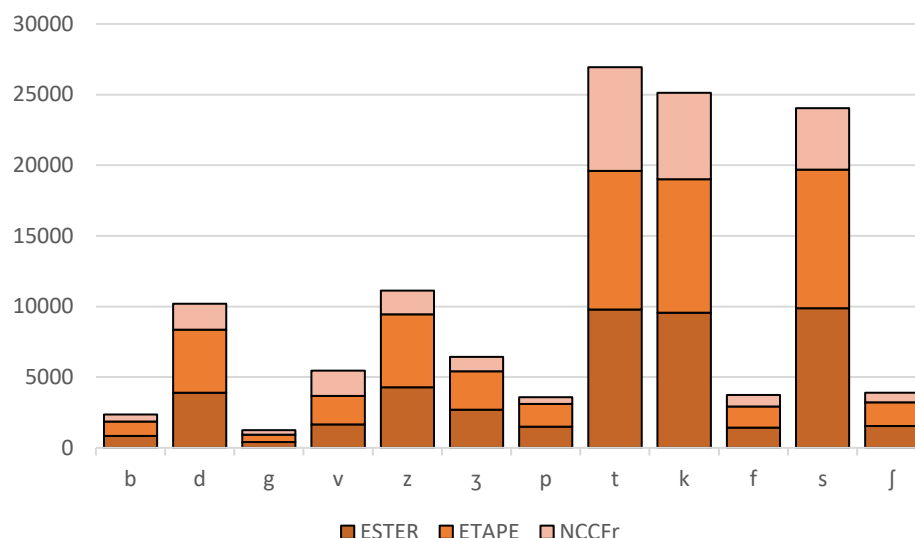
A subset of the data was manually verified to ensure that the absence or presence of word-final schwas had been accurately identified by the system. The first author, a native speaker of Standard French, listened to 1260 tokens (35 tokens for each coda in each corpus), i.e. approximately 1% of the dataset. When schwa was falsely transcribed or omitted, or when a single doubt could be cast on the transcription, she considered the transcription as inaccurate. The result leads us to estimate that the ASR system used to detect schwa is over 92% accurate.

Combining these three large corpora, our data contains a total of 124,198 tokens. Among them, regardless of whether they are followed by schwa or not, roughly 70% end in an underlyingly voiceless consonant and 30% in an underlyingly voiced consonant. The distribution across the three corpora of each word-final coda (henceforth referred to as “coda”) is given in Table 1.

Table 1. Number of each coda in each of the three corpora.

	b	d	g	v	z	ʒ	p	t	k	f	s	ʃ	All
ESTER	832	3901	416	1661	4283	2692	1492	9792	9560	1428	9883	1538	47478
ETAPE	1022	4468	513	2004	5159	2724	1618	9798	9453	1495	9815	1693	49762
NCCFr	509	1839	328	1792	1692	1025	476	7348	6120	814	4346	669	26958
ALL	2363	10208	1257	5457	11134	6441	3586	26938	25133	3737	24044	3900	124198

As can be seen in Figure 1, the most frequent coda across all three corpora is /t/ (21.69%), followed by /k/ (20.24%) and /s/ (19.36%). The least frequent coda is /g/ (1.01%).

Figure 1. Number of tokens for each coda in each corpus

Concerning the realization of schwa in word-final position, across all 124,198 schwa-sites, there are 16,645 final schwas (13.40%). Among the 49,762 schwa-sites in ETAPE, there are 6505 final schwas (13%), which is consistent with Purse (2019)’s own transcriptions of a subset of ETAPE and BREF80, where he found an average 15% of schwa realizations in journalistic speech.

In the following, we focus on speech style (Section 4.1.1) and gender of the speaker (Section 4.1.2) as well as orthography (Section 4.2) before investigating phonotactic (Section 4.3.1) and phonetic/phonological factors such as the left (Section 4.3.2) and right (Section 4.3.3) contexts, the sonority sequence of the immediate environment (Section 5) and speech rate (Section 6) in the realization of final schwa in Standard French.

4. Results: Factors favoring or disfavoring word-final schwa in French

It is not an easy task to show a clear pattern in the various factors favoring or disfavoring word-final schwa in Standard French and previous studies do not always converge towards a unitary global picture. Orthography and phonotactics have received an extensive attention but other factors have been less investigated. We therefore propose an overview of the factors favoring or disfavoring word-final schwa in Standard French on the basis of the three large corpora.

To that extent, we conducted a statistical analysis in R (R Development Core Team 2008), using a generalized linear model³. This model includes the following predictors: corpus (ref. = ESTER), speaker gender (ref. = Female), orthography (ref. = no graphic <e>), number of surrounding consonants (ref. = 2 consonants in a row), the coda’s manner of articulation (ref. = fricative), place of articulation (ref. = alveolar)

³ We agree that a glmm would have been ideal, allowing us to include interactions in the model and to add random effects. Unfortunately, this was *not* possible for technical reasons: The unprecedented amount of data used for this study did not allow a glmm to converge.

and laryngeal feature (ref. = voiced), and finally the type of the first phoneme of the following word (or pause) (ref. = voiceless obstruent). The results for each factor are described in the corresponding subsection and show that all factors influence the realization of word-final schwa to some extent, even in a model taking all factors (except sonority and speech rate) into account at the same time.

4.1. Sociolinguistic factors

Many previous studies have stressed the importance of sociolinguistic factors in the realization of final schwa. Among them, two are particularly relevant and have been studied in large corpora: speech style and gender of the speaker⁴.

4.1.1. Effect of speech style

Speech style is a relevant factor influencing the realization of schwa in continuous speech in word-initial syllable (Wu et al. 2016, 2017) and in word-final position (Adda-Decker et al. 1999, Milne 2014).

In order to estimate the corresponding realization in word-final position, we calculate the rate of automatically aligned word-final schwas in the three corpora. Our three databases indeed reflect three different speech styles. ESTER is representative of semi-prepared, careful, possibly read speech; ETAPE 1 and 2 of mixed semi-prepared monologues and several-speaker conversations; and NCCFr of casual friendly speech.

Table 2 shows that ESTER contains the most word-final schwas (17%) and NCCFr the least (7.68%).

Table 2. Number of word-final schwas by corpus.

	No schwa	Schwa	% Schwa
ESTER	39409	8069	17.00
ETAPE	43257	6505	13.07
NCCFr	24887	2071	7.68

In Table 2, one can see that the more formal the corpus, the more schwa realizations. The results from the general linear model show that the probability to observe a word-final schwa decreases significantly both in ETAPE (estimate = -0.30631, std error = 0.01850, $p < 0.001$) and in NCCFr (estimate = -0.92817, std error = 0.02709, $p < 0.001$), with respect to that observed in ESTER.

In our data, formal speech styles are therefore associated with a higher rate of schwa realizations. This indicates that word-final schwa in Standard French could be similar to an intrusive vowel (Hall 2006) in that it is more realized in careful speech, in which we expect a more careful pronunciation and therefore more audible consonantal releases (Picheny et al. 1986).

4.1.2. Effect of gender

⁴ Age was not included in our study because this information is not available for most of the speakers in the ESTER and ETAPE corpora. It could be a confounding factor, since such corpora from “official” sources such as TV and radio are expected to have older speakers than NCCFr (mean age: 22;22). However, Slawinsky (1991) did not find an effect of age on consonantal release in English.

Previous studies are unclear on whether the gender of the speaker is a decisive factor in the realization of schwa (Wu et al. 2017 vs Purse 2019). The question therefore arises as to whether our three corpora display more word-final schwa in female speech than in male speech, thus aligning with Wu et al. (2017) and Adda-Decker and Lamel (2005), or if there is no effect of gender whatsoever, thus aligning with Purse (2019)'s results.

Note that the gender of some speakers was unidentified in the original database, especially in the ETAPE corpora, so we removed 582 tokens from the original 124,780 tokens, thus leaving us with 32,845 tokens uttered by female speakers and 91,353 by male speakers. The distribution across the three corpora, along with the percentages of uttered word-final schwas, is presented in Table 3.

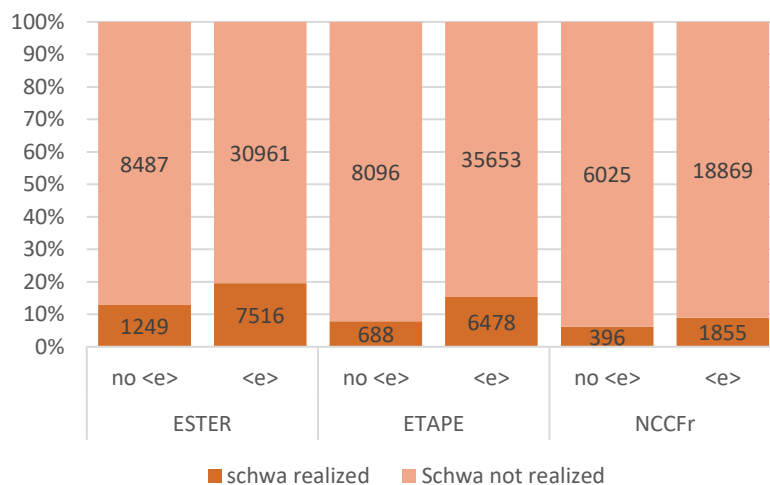
Table 3. Number of tokens by female and male speakers by corpus.

	Female		Male		Unknown gender
	<i>Number of tokens</i>	<i>% of schwas</i>	<i>Number of tokens</i>	<i>% of schwas</i>	
ESTER	10,183	17.50	37,295	16.86	36
ETAPE	9,646	13.66	40,116	12.93	546
NCCFr	13,016	8.69	13,942	6.74	0

In Table 3, the rates of schwa realization are systematically higher in female speech rather than in male speech, and the difference is bigger in less formal speech (ESTER: $\Delta = 0.64\%$, ETAPE: $\Delta = 0.73\%$ vs NCCFr: $\Delta = 1.95\%$). Consistently with the previous literature on word-internal schwa, women have a higher rate of schwa realisation than men and this difference is statistically significant (estimate = -0.10342, std error = 0.02018, $p < 0.001$).

4.2. Orthography

Although Standard French is believed to have lost the phonological distinction between words such as *seul* 'alone (masculine)' and *seule* 'alone (feminine)', Purse (2019) finds an effect of this distinction in Standard journalistic speech, suggesting an effect of orthography. The rate of word-final schwa is computed here as a function of the presence or absence of a final graphic <e>. Figure 2 shows word-final schwa realization as a function of orthography depending on the corpus.

Figure 2. Realization of word-final schwa as a function of orthography by corpus

Journalistic speech, that can sometimes be read aloud, generally shows a more important gap than spontaneous casual speech. In ESTER, 19.53% of words ending in a graphic <e> are realized with word-final schwa, as opposed to 12.83% of words not ending in a graphic <e> ($\Delta=6.70\%$). Similarly, in ETAPE, 15.38% of words ending in a graphic <e> are realized with word-final schwa, as opposed to 7.83% of words not ending in a graphic <e> ($\Delta=7.55\%$)⁵. However, in NCCFr, orthography has a much smaller effect, with only 8.95% of words ending in <e> realized with word-final schwa as opposed to 6.17% of words not ending with <e> ($\Delta=2.78\%$). The probability to observe a word-final schwa increases significantly for words with graphic <e>, compared to what is observed for words without graphic <e> (estimate = 0.59076, std error = 0.02620, $p < 0.001$).

As a transitional conclusion, we would like to highlight the fact that the results on sociolinguistic factors of schwa realization are contradictory with regards to its status: On the one hand, schwa is realized at different rates across speech styles and genders, suggesting its excrescence-like optionality, but on the other hand, the effect of orthography suggests that it is embedded somewhere in the grapho-phonological representations.

4.3. Phonotactic and phonological factors

In the following subsections we consider the phonological conditions responsible for the realization of word-final schwa in Standard French, along with more detailed observations about the string of consonants before and after schwa (Section 4.3.1), the precise nature of the coda (Section 4.3.2) and the right context (Section 4.3.3).

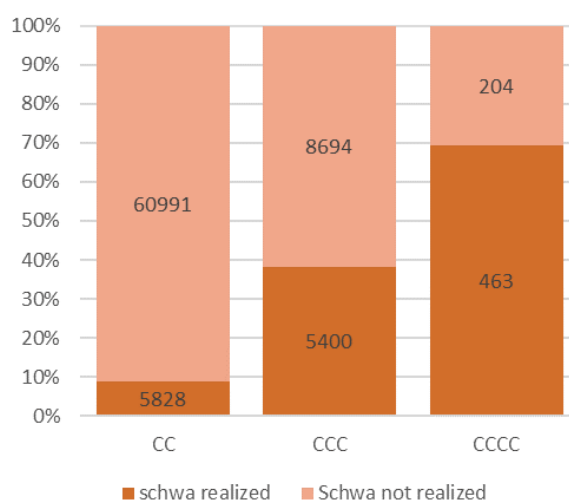
⁵ Although orthography could be considered as a cross-factor of the corpora, ESTER and ETAPE behave similarly as opposed to NCCFr: Since ESTER was mostly prompted speech but not ETAPE, this shows that reading aloud is not the cause of the effect of orthography on schwa realization.

4.3.1. The ‘Three Consonants Rule’

According to Grammont (1894), the realization of schwa becomes mandatory in most cases when the surface form resulting from the absence of schwa would have three or more consonants in a row. In line with previous findings, we address the question of word-final schwa realization as a function of the number of surrounding consonants.

Figure 3 displays the rate of word-final schwas surfacing as a function of the number of consonants. Note that CCC can stand either for a sequence of a simplex coda followed by a complex onset (C#CC, e.g. *groupe spécialisé*, ‘specialized group’: /gʁup.spesialize/) or vice-versa (CC#C, e.g. *divorce financé*, ‘divorce financed...’: /divɔʁs.finãse/).

Figure 3. Realization of word-final schwa as a function of consonantal sequence in all three corpora



If the sequence without schwa would surface as a single coda followed by a single onset, i.e., two consonants in a row (CC), schwa is realized in only 8.72% of the cases. If the sequence would surface as three consonants in a row (CCC), schwa is realized in 38.31% of the cases ($\Delta = 29.59\%$, estimate = 0.28029, std error = 0.04089, $p < 0.001$). Finally, if the sequence would surface as four consonants or more (CCCC), schwa is realized in 69.41% of the cases ($\Delta = 60.69\%$), however, this difference is not statistically significant (estimate = 0.07212, std error = 0.06934, $p > 0.05$).

A secondary analysis also showed that, when followed by pause, words ending in a simplex coda tend to display fewer schwas (25.80%) than words ending in coda clusters (35.87%, $\chi^2=74.802$, $df=1$, $p < 0.001$). This behavior is similar to that reported by Hansen and Mosegaard-Hansen (2002) for the Parisian “parasite schwa”.

To this regard, word-final schwa displays similarities with intrusive schwa in that it breaks complex clusters (Hall 2006) but is also consistent with the definition of epenthesis as a repair strategy against syllable markedness (Hall 2011) in that it helps avoid complex codas.

4.3.2. Nature of the coda

In this subsection, we focus on the left context specifically, i.e., at the consonant preceding schwa-site.

Table 4 shows that, overall, /d/ is the consonant most frequently followed by schwa (23.91%) and /f/ the one least followed by schwa (6.83%)⁶. To avoid a bias due to the Three Consonants Rule, the numbers in this table are limited to simplex codas followed by pause, vowel or simplex onset (n=105,718).

Table 4. Number of schwas after each simplex coda before pause, vowel or simplex onset (all corpora combined).

Coda	No schwa	Schwa	% Schwa
<i>d</i>	6605	2076	23.91
<i>v</i>	4374	772	15.00
<i>g</i>	1003	167	14.27
<i>ʒ</i>	4879	671	12.09
<i>b</i>	1848	236	11.32
<i>z</i>	9468	1143	10.77
<i>p</i>	3045	344	10.15
<i>s</i>	19642	1716	8.03
<i>k</i>	19689	1708	7.98
<i>t</i>	18342	1564	7.86
<i>ʃ</i>	2700	211	7.25
<i>f</i>	3275	240	6.83

In general, voiceless obstruents are less frequently followed by schwa than voiced ones (estimate = -0.36216, std error = 0.01919, $p < 0.001$) and fricatives less than stops (estimate = 0.63756, std error = 0.01868, $p < 0.001$). Rialland (1986) already suggested an effect of fricatives on schwa deletion specific to French, but what is notable here is that voiced stops have been shown in the literature to display more audible releases (Wang 1959).

Moreover, if the data is split into labial obstruents /p, b, f, v/, alveolar obstruents /t, d, s, z/, and posterior/velar obstruents /k, g, ʃ, ʒ/, the results show that, with regards to schwa realization, labials favor schwa realization less than alveolars (estimate = 0.06955, std error = 0.02832, $p < 0.05$) and posterior-velar consonants more (estimate = 0.09339, std error = 0.02028, $p < 0.001$). This is consistent with the phonetic literature, since velars have been argued to be subject to more audible releases than alveolars and labials (Householder 1956, Halle et al. 1957, Malécot 1958, Wang 1959).

The above results indicate that the effect of the laryngeal feature is consistent with the findings of Hansen and Mosegaard-Hansen (2002) about parasite schwa. Moreover, an effect of both place and manner of articulation has been demonstrated. The effects of all these characteristics of the consonant imply that the nature of word-final schwa in Standard French could be similar to that of an excrescent vowel resulting from the audible release of the constriction.

⁶ On a side note, this result is interesting *per se* because it shows that synchronic variation parallels diachrony: French /d/ could not be maintained if not followed by schwa, but /f/ could, as in *veuf*, ‘widower’, *vif*, ‘lively’...

4.3.3. Effect of immediate right context

To provide an overall picture of the effect of the context on schwa-site, after considering the nature of the preceding consonant, we focus on the following context across the word-boundary.

Again, to avoid the unwanted effect of the Three Consonants Rule, the numbers in Table 5 are limited to simplex codas followed by pause, vowel or simplex onset (n=105,718). As one can see from Table 5, when looking at all three corpora and all twelve codas together, the effect of the right context is not surprising (Jatteau *et al.* 2019a, 2019b): The prepausal context favors schwa the most (25.45%). This is confirmed by the generalized linear model conducted on the entirety of the data. Compared to what is observed for voiceless obstruents, the possibility to observe a word-final schwa increases significantly before pauses (estimate = 1.20904, std error = 0.04381, $p < 0.001$), sonorants (0.15615, std error = 0.02802, $p < 0.001$) and voiced obstruents (estimate = 0.11682, std error = 0.02478, $p < 0.001$), but decreases significantly before vowels (estimate = -0.12632, std error = 0.04362, $p < 0.01$).

Table 5. Number of schwas for each right context (simplex coda before pause, vowel or simplex onset only, all corpora combined)

Right context	Pause	Vowel	Sonorant	Voiced obstruent	Voiceless obstruent
<i>No schwa</i>	8915	24973	13659	19325	27998
<i>Schwa</i>	3043	2308	1553	1938	2006
% Schwa	25.45	8.46	10.21	9.11	6.69

Even though the effect of following vowels is negative compared to voiceless obstruents, we can still observe 8.46% schwa realization in this environment. Since this is rather surprising, the right context was looked at more finely to find out whether particular vowels tend to favor schwa more than others.

Figure 4. Vocalic space with numbers and rates of schwa realized before each vowel in all three corpora.

i 8.26 % 204 / 2471	y 6.18 % 60 / 971	u 9.65 % 90 / 933
e 10.10 % 545 / 5395	ø 8.55 % 26 / 304	o 8.04 % 185 / 2302
ẽ 8.64 % 279 / 3230		õ 10.51 % 131 / 1246
ɛ 7.86 % 107 / 1362	œ 1.71 % 8 / 468	ɔ 12.36 % 76 / 615
	a 8.68 % 668 / 7695	ã 8.24 % 323 / 3919

Unsurprisingly, the vowel disfavoring schwa the most is the mid-low rounded vowel [œ], which tends to merge with schwa in connected speech, with only 1.71% schwa realization. This small amount of schwa realization can be considered as an

error margin from the ASR system. However, as one can see from Figure 4, the vowels most preceded by schwa are the mid-high vowel [e] (10.10%), the mid-low vowels [ɔ] (12.36%) and its nasalized counterpart [ɔ̃] (10.51%) and, to some extent, the high vowel [u] (9.65%).

In conclusion, final schwa seems to be dependent on the articulation of preceding consonant and could thus be considered an excrescent vowel. However, the role of the Three Consonants Rule is ambiguous: it shows that schwa occurs in heterorganic clusters, like excrescent vowels, but also that it repairs illicit structures, like epenthesis. The consonant clusters resulting from the absence of schwa will thus be investigated in the next Section.

5. Effect of the sonority sequence

Two additional points appear to be important to establish the status of final schwa and are thus investigated independently of the statistical model used in Section 4: the role of the Sonority Sequencing Principle and Sonority Distance in C(ə)#C sequences (this section), and the role of speech rate (Section 6).

Since a full study of the effect of the Sonority Sequencing Principle and Sonority Distance would exceed the scope of this paper, we will limit ourselves here to point out that in our data, sonority has an effect even in C(ə)#C sequences, that is, simplex codas followed by simplex onsets (n=66,146). Note that our corpus is limited to obstruent-final consonants, so that the sonority profiles of the C#C sequences are unbalanced (obstruents only for the left context vs obstruents, sonorants and glides for the right context).

As can be seen in Table 6, when the sonority between the coda and the following onset is falling (e.g. [dispozitif.pyblik], ‘public system’), schwa is realized in 6.49% of the cases, whereas it is realized in 9.50% of the cases when it is rising (e.g. [øʁɔp.sɑ̃tʁal], ‘Central Europe’). When the sonority plateaus (e.g. [ɔ̃z.zuʁ], ‘eleven days’), schwa is realized in 8.26% of the cases. These results are significant ($\chi^2 = 153.44$, $df = 2$, $p < 0.0001$) and show that word-final schwa does not behave like its word-internal counterpart, which tends to disappear in rising sonority sequences (Côté 2000, Bürki 2011).

Table 6. Number and rates of schwa according to the sonority sequence of a simplex coda followed by a simplex onset.

	No Schwa	Schwa	% Schwa
<i>Falling</i>	20225	1404	6,49
<i>Plateau</i>	11716	1055	8,26
<i>Rising</i>	28730	3016	9,50
<i>Total</i>	60671	5475	8,28

Moreover, among plateaus, schwa is more likely to be realized if the coda and the following onset are the exact same consonant (11.77% schwa realization) than if they are not (6.14%). This is true for each corpus, even though the difference between sequences of identical vs different consonants with regards to schwa realization is

more important in more formal speech (ESTER: $\Delta=7.58\%$; ETAPE: $\Delta=5.90\%$; NCCFr: $\Delta=2.20\%$). This result is significant ($\chi^2 = 126.92$, $df = 1$, $p < 0.0001$). Since, in Hall (2006)'s view, homorganicity of consonants disfavors intrusive schwa insertion, this result provides an additional argument to not consider word-final schwa as an excrescent vowel. On the other hand, it provides a first hint that schwa could be used as a repair strategy to comply with an OCP constraint against identical adjacent segments, and thus that it functions as an epenthetic vowel.

However, a more generalized analysis of Sonority Distance provides contradictory results. We used a metric of Sonority Distance adapted from Gouskova (2002) that we present in Table 7.

Table 7. Sonority Distance between C1 (last consonant of the first word) and C2 (first consonant of the second word).

C1 \ C2	ptk	fsf	bdg	vz3	mn	l	κ	wj
ptk	0	1	2	3	4	5	6	7
fsf	-1	0	1	2	3	4	5	6
bdg	-2	-1	0	1	2	3	4	5
vz3	-3	-2	-1	0	1	2	3	4

From our results on homorganic sequences, we could have been led to believe that the smaller the distance between C1 and C2, the more schwa realized: This is what would be predicted if schwa insertion were an epenthesis driven by an OCP-constraint against similar segments. However, this is not what the present results show. As can be seen in Table 8, although the Sonority Distance is a significant factor ($\chi^2 = 425.53$, $df = 10$, $p < 0.0001$), it does not follow a linear rise in schwa realization.

Table 8. Schwa realization rates as a function of Sonority Distance.

Sonority Distance	No schwa	Schwa	% Schwa
-3	4111	266	6,08
-2	3048	430	12,36
-1	9771	613	5,90
0	11716	1055	8,26
1	12816	870	6,36
2	7578	956	11,20
3	3348	448	11,80
4	3279	346	9,54
5	4192	387	8,45
6	690	88	11,31
7	122	16	11,59
Total	60671	5475	8,28

This is also true when only the distance is taken into account and not the direction of the sonority profile (i.e., when merging the 1 and -1, 2 and -2 and 3 and -3 sets). This shows that schwa does not have the function to avoid similarity, only identity. Thus, either word-final schwa does not fully function as an epenthetic segment, or Standard French does not have a strong OCP-constraint against similar segments (only against identical ones). In the latter case, schwa inserted between two identical consonants would be epenthetic, while those inserted between two similar consonants would either be epenthetic (for other reasons, such as the Three Consonants Rule) or intrusive.

6. Speech rate

To investigate whether speech rate has an effect on word-final schwa, we estimated speech rate as the number of phones (consonants and lexical vowels) per second for each speech turn. The number of word-final schwas (non-lexical vowels) is established for each speech turn. A Pearson's test was operated on the data for each corpus.

Very weak correlations were observed between speech rate and word-final schwa realization in all corpora (ESTER: $r=-0.03$, ETAPE: $r=-0.01$, and NCCFr: $r=0.20$). Although this result might be an artifact due to the fact that the relevant factor in variation phenomena is not how quick or slow one speaks but how regular the rhythm of the speech is, it seems to indicate that indeed speech rate does not influence schwa realization in Standard French.

Thus, although we need to take this result with caution, it suggests that word-final schwa in Standard French is not impacted by speech rate, which is consistent with Hall (2006)'s definition of an epenthetic vowel as opposed to intrusive vowels.

7. Discussion: Word-final schwa in Standard French, intrusive or epenthetic?

In this study, sociolinguistic, orthographic, phonotactic and phonetic / phonological factors have been investigated and all except speech rate seem to affect the realization or non-realization of schwa in word-final position in Standard French.

Our generalized linear model indicates that one predictor in favor of schwa realization is speech style. This is in line with Adda-Decker et al. (1999) and Milne (2014) but contrasts with Eychenne (2019) who found no effect of the task in Meridional French (conference vs reading task vs interview vs conversation) but found one in Standard French (prepared read speech vs interview vs conversation). Similarly, gender is a significant factor in schwa realization in our model for Standard French, while it was not in Purse's results on the same variety. This variability across speaking situations and speakers allows to posit that word-final schwa is correlated with a careful speech style in Standard French. As mentioned before, this might indicate that word-final schwa in Standard French has similarities with intrusive vowels, since it is more realized in speech styles where codas are possibly more audibly released. Moreover, the fact that place and manner of articulation and laryngeal feature of the coda are also weighing in the model could show that word-final schwa in Standard French is a kind of intrusive vowel resulting from the coda's release burst.

However, the fact that the homorganicity of the consonants surrounding schwa-site favors schwa realization suggests that defining word-final schwa as an excrescent vowel may be erroneous. This is supported by the fact that our model also indicates that orthography plays a role, thus suggesting that schwa is present at some level of representation. Moreover, results showed that final schwa in Standard French could be a repair strategy against syllable markedness, because its realization allows the production of typologically rare VC# or VCC# sequences to be avoided (which it does not in Southern varieties where schwa is lexical). Finally, word-final schwa in Standard French does not seem to be affected by speech rate, which is further evidence that it functions as an epenthetic segment, as opposed to an intrusive vowel that is supposed to disappear at fast speech rates.

As a conclusion, one could argue that word-final schwa in Standard French is similar to an intrusive vowel to some extent, in particular given its realization after consonants favoring audible releases. However, word-final schwa in Standard French also behaves like an epenthetic vowel on many levels: It repairs typologically illicit codas – and the more complex the coda, the more schwa realizations – but it also repairs heterorganic clusters less than homorganic ones, and it is not impacted by speech rate. This might indicate that Standard French is in an in-between state, where final schwa behaves like an intrusive vowel to some extent, but also like an epenthetic vowel to a much larger one. This could also mean that French final epenthesis is characterized by phonetic properties close to those of consonantal releases, as if consonantal release were exploited on the phonological level. This brings us to conclude that schwa-site, i.e. the possibility for the realization of word-final schwa in Standard French, should probably be included in the representations, not as a lexical vowel that could be deleted, but for instance as an empty syllabic nucleus (Anderson 1982), as an empty V-slot in Strict CV (Lowenstamm 1996) or as a C/V transition in the contour-based approach of Strict CV (Brandão de Carvalho 2017, Hutin 2018). Such proposals will be the topic of future research.

The ambivalent nature of schwa was already shown in Finnish (Karlin 2021), but in this language, schwa is argued to be originally an excrescent vowel progressively gaining a phonological status. In the present paper, we deliberately make no claim regarding the (micro-)diachronic process involved since the nature of schwa is investigated from a synchronic, functional point-of-view. That being said, if an excrescence can indeed become phonologized, can an epenthesis, i.e. a repair strategy, actually become an excrescence? The epenthetic schwa could be only not realized often enough and leave enough space in the speech flow for excrescent vowels to be realized. This in turn would beg the question as to whether what we have observed is actually two distinct objects perceived as one by the system (and, supposedly, by the speakers) or one and the same object with ambivalent (evolving) properties. Given the principle of Ockham's razor, we would argue that the latter is more acceptable than the former, but the exact argumentation and implications for the micro-diachrony of French should remain the topic of future research.

The present extended study of word-final schwa in Standard French benefited from access to large-scale data and automatic speech alignment techniques. There is little doubt that several of the points discussed here would have been much more difficult, if not impossible, to study as finely without them. This study is therefore not only interesting for the knowledge it brings us regarding word-final schwa in French and epenthesis in general, but also displays an example of what that kind of technology

can bring to linguistic inquiry of fine-grained variation. Further studies should use such methodologies to study word-final schwa after nasals and liquids as well, and to investigate the exact phonetic properties of these schwas.

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