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Diachronic aspects of stressed schwa

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Stressed schwa in languages and dialects such as Bulgarian and Gardenese Ladin resembles unstressed schwa in being short and exhibiting a highly variable articulatory configuration. Sound change data reveal the existence of an asymmetry between those vowels that stressed schwa may emerge from and those vowels that stressed schwa may give rise to: the former are essentially short high front, mid high front and short low and, therefore, relatively short and spectrally analogous to the mid central vowel; the latter are mostly [ɛ] and [a], which indicates that only spectral similarity, not segmental shortening, is at work in this case. Results from a vowel identification test using as stimuli productions of stressed /ə/ by Majorcan Catalan speakers reveal that whether stressed schwa is identified as /ɛ/ or as /a/ (and less so as /e/ or as /ɔ/) to a large extent depends on consonantal context, thus suggesting that consonant-dependent coarticulatory effects may be involved in the categorization of schwa as another vowel in sound change. The study also shows that stressed schwa may be generated through assimilation to some specific consonants, and possibly to instances of unstressed schwa available in the same word as well, which is consistent with a universal trend for schwa to occur in stressed position provided that it is also available in unstressed syllables.

KEYWORDS: stressed schwa, sound change, vowel-consonant coarticulation.

1. Introduction

The stressed position may be considered to be a relatively unnatural site for schwa to occur. This is so since schwa is expected to be the outcome of vowel reduction and, thus, to be generated through segmental shortening and articulatory undershoot in appropriate conditions such as at fast speech rates and in syllables which do not carry stress (Silverman 2011, and see also Hannahs 2013: 53 regarding a similar concern about the placement of reduced vowels in stressed position). As reviewed in a previous study (Recasens 2022), stressed schwa may nevertheless be found in a considerable number of language families showing lexical stress, which are listed next together with one or more representative languages and dialects within parentheses: Albanian, Amazonian (Apinajé, Sanumá), Australian (Arrernte), Austro-Asiatic (Khmer, Car Nicobarese), Austronesian (Javanese, Malay, Balinese), Caucasian (Kabardian), Celtic (Welsh), Germanic (English RP, as in the [ɜː] of *nurse*; Wells 1982: 304), Iranian (Kurdish, Pashto), Niger-Congo (Ndut), N. American Indian (Salishan languages), Papuan (Sentani), Romance (Romanian, Gardenese Ladin, Piedmontese, Majorcan Catalan), Semitic (Amharic), Slavic (Bulgarian, and also Slovene, which has both stress and tones; Lencek 1982: 160-166), Turkic (Tatar) and Uralic (Cheremis, Nganasan).

In order to identify the phonetic and phonotactic characteristics of stressed schwa, in our 2022 study we looked first into the stress patterns of those languages which have been described as exhibiting schwa in stressed position. Whenever the stress pattern was absent or unclear, schwa was taken to occur in a prominent syllable whether placed in monosyllables endowed with full semantic content or embedded in longer words whose vowel nuclei were schwa exclusively. This situation applies to tone languages as well as to languages with no tones and an uncertain stress pattern in which the term ‘stressed’ should be rather taken to mean ‘prominent’. Among the former we may cite language families such as Bantu (Nen), Chadic (Margi), Niger-Congo (Mono), Sino-Tibetan (Pumi, Mandarin Chinese) and Tai-Kadai (Thai), and among the latter, Indo-Aryan (Gujarati, Hindi) and Mongolic (Bonan, Daghur).

The difficulty involved in combining vowel centralization and stressed position proved to be consistent with certain phonetic properties of stressed schwa. The acoustic data subjected to analysis in our previous study showed that, whether unspecified for vowel length or counting as short in languages which set short and long vowels in phonemic contrast, stressed schwa turned out to be in many respects less prominent than any peripheral mid and low vowel and even less prominent than high vowels. This difference is manifested both by the vowel articulation and acoustic characteristics – see (i) below –, and by vowel duration – see (ii).

(i) At least for a representative number of languages endowed with stressed schwa, this vowel happens to be highly sensitive to coarticulatory effects exerted by the contextual consonants and therefore lacks a well-defined articulatory target. These effects are likely to occur at the tongue predorsum rather than at the tongue back since, as previously suggested (Browman & Goldstein 1992), schwa may be articulated with some postdorsal constriction at the pharynx rather than being fully unconstricted. Moreover, this is expected to be the case for stressed schwa rather than for unstressed schwa, as suggested by acoustic data from our previous study showing a lower F2 and a slightly higher F1 for the former *vs* latter vowel variant in a number of languages, which could be indicative of differences in tongue body retraction.

This high degree of variability may explain why the vowel of interest can be characterized diversely as mid central or as mid back unrounded and, thus, as [ə] or as [ɤ] or [ʌ]. Indeed, acoustic evidence from several languages considered to have stressed schwa reveals that it is produced as mid central though slightly leaning towards the mid back unrounded area of the vowel space, and oscillating between mid high and mid low (and thus including realizations such as [ɘ], [ɜ], [ɐ]) depending on the number of peripheral mid vowels available in the vowel system. This scenario applies to languages such as Paicî (Gordon & Maddieson 1996), Iaai (Maddieson & Anderson 1994) and Ngwe (Ladefoged 1968: 35-36) in which stressed schwa appears to be mid central acoustically in spite of being commonly transcribed as [ɤ]. The present investigation also deals with data taken from languages and dialects where the vowel of interest has been assigned a number of the phonetic symbols just mentioned even by different scholars working on the same language (e.g. Thai [ə], [ɤ], Bulgarian [ə], [ɜ], [ɤ], Romanian [ə], [ʌ]). This scenario follows from the fact that these vowel sounds are highly similar perceptually and also that, as just stated, stressed schwa is highly variable acoustically as a general rule.

(ii) Stressed schwa counts often as short in languages exhibiting a vowel length distinction and tends to be the shortest of all available vowels in other languages where this is not the case, while often occurring in word positions which favour segmental shortening. Thus, for example, in Piedmontese and Francoprovençal dialects, this vowel occurs essentially in checked syllables, in paroxytones ending in a low vowel and in Latin proparoxytones (i.e. etymological proparoxytones, as explained below) and in Mandarin Chinese, the more constricted and longer vowel allophone [ɤ] is found in open syllables and the less constricted and shorter vowel cognate [ə] appears in syllables checked mostly by a nasal consonant. Also in the Salishan languages stressed schwa is found mainly in closed syllables and happens to be reluctant to receive stress unless all other vowels in the same word are schwa, central and/or short peripheral (Kinkade 1998). This is not to say, however, that stressed schwa should be specified necessarily as a short vowel. Thus, in Iaai all vowels including schwa may be short or long (Maddieson & Anderson 1994), and regarding English, [ɜ], as in *nurse*, is transcribed as a long vowel in Southern British English and the American English cognate [ɝ] turns out not to be particularly short (Umeda 1975, Van Santen 1992).

Within this scenario, the present study will investigate the extent to which various diachronic phenomena involving stressed schwa are associated with the phonetic and phonotactic characteristics referred to so far. The motivation for looking into these sound changes from a diachronic perspective is that it is most unnatural for an unconstricted, short and highly coarticulation-sensitive vowel such as schwa to act as the nucleus of stressed syllables. The trend towards disfavouring stress on less sonorous vowels, i.e. higher *vs* lower (and thus shorter *vs* longer) and central *vs* peripheral (and thus less constricted *vs* more constricted) has been pointed out in the phonology literature (Kenstowicz 1997, de Lacy 2004). This special vowel status is in accordance with the observation for the vast majority of the languages cited in our previous study that the presence of schwa in stressed position implies its presence in unstressed syllables while the reverse does not generally hold.

The paper is divided in the following sections. An important topic which will be addressed in sections 2 and 4 is the extent to which those vowels from which stressed schwa originates differ from the vowels that stressed schwa may be replaced by in sound change. Section 3, on the other hand, is about those sound change mechanisms which should play a role in the genesis of stressed schwa. Several testing hypotheses will be enounced at the beginning of each section and evaluated against data from the world's languages, which may be considered fairly representative in so far as the sound changes under analysis belong to a number, albeit small, of unrelated and geographically distant language families. A problematic aspect which happens to be inevitable in studies on diachronic phonology is that the phonetic quality of the source vowels from which other vowels have arisen may be somewhat uncertain since it has often been reconstructed by scholars and consequently does not correspond to actual vowel productions.

2. Genesis of stressed schwa

As to the first issue, the vowel source of stressed schwa, it is hypothesized that to the extent that stressed schwa is inherently short it should originate from peripheral vowels which are also relatively short and, thus, mostly from (mid) high vowels (it is a well-known fact that vowel duration and intensity increase with vowel opening and, thus, in the progression 'low vowels > mid low vowels > mid high vowels > high vowels'; Peterson & Lehiste 1960). This principle should of course not hold in languages in which stressed schwa or a related vowel variant is considered to derive from schwa in the proto-language, as in the case of Malay (Prentice 1987: 919), Chinese (Baxter 1992: 340-342, Norman 2005: 47), Thai (Li 1977: 261) and languages of the Austronesian family (Blust 2013: 590). For the same reason, stressed schwa should emerge preferably from short vowels in languages which set vowel length in phonological contrast, and otherwise in those positional conditions within the syllable and the word which cause vowels to shorten such as in checked *vs* open syllables and in the word-medial *vs* word-initial or word-final position.

Moreover, the centralization of peripheral vowels to stressed schwa is expected to be conditioned not only by segmental duration but also by spectral similarity and, therefore, to operate on front vowels and /a/ rather than on back rounded vowels. Spectral affinity is based on articulatory considerations (just as schwa, mid front and low vowels involve no lip rounding), as well as on spectral configuration data showing that, as revealed by data for Catalan (Recasens & Espinosa 2006), an F2 for schwa at about 1500 Hz lies closer to F2 for /e/ (around 1800-1900 Hz), /ɛ/ (1650-1750 Hz) and front /a/ (1350-1450 Hz) than for /ɔ/ (1100-1200 Hz) and /o/ (1000-1050 Hz).

Data on those source vowels which can give rise to stressed schwa will be reviewed in sections 2.1, 2.2 and 2.3 for high, mid front and low and mid back vowels, respectively.

2.1. High vowels

Stressed schwa may emerge from high vowels, which are the shortest peripheral vowels of vowel systems, and more specifically whenever these vowels count as short and may thus be represented as /ɪ/, *ĭ* and /ʊ/, *ŭ*.

The source of stressed schwa are the Proto-Slavic jers *ĭ* and *ŭ* in several Slavic languages: in N.W. Bulgarian dialects, though only *ŭ* in Standard Bulgarian, where *ĭ* has yielded a mid front vowel ([dɛn], [dən] < **dĭn* 'day', [sən] < **sŭn* 'dream'; Vaillant 1950: 128-129, Carlton 1990: 303); in N. Macedonian dialects, as opposed to Standard Macedonian, where *ĭ* and *ŭ* have shifted to *e* and *o*, respectively ([dɛn], [dən] 'day', [sɔn], [sən] 'dream'; Friedman 2001: 7); in Kashubian, where words like *lëpa* 'lime' and *lëdze* 'people' with stressed schwa correspond to *i* and *u* in the Polish cognates *lipa* and *ludzie* (Stone 1993: 765); and in Slovenian, where stressed *ĭ* and *ŭ* (also unstressed high vowels) have been replaced by schwa in several dialects ([sət] *sit* 'full', [kəp] *kup* 'heap') including present-day colloquial Ljubljana speech, where the standard form [nitʃ] *nič* 'nothing' bearing a grave tone is pronounced as [nətʃ] (Petek *et al.* 1996, Greenberg 2006: 19).

The short high front and high back vowels are also at the origin of stressed schwa in non-Slavic languages. This is so for Welsh, where stressed schwa occurs in non-final syllables of polysyllabic words, as exemplified by the vowel mutations [ɨ] *byd* 'world' SG ~ [ə] *bydoedd* 'world' PL from Proto-Brythonic **bĭd*, and [u] *trwm* 'heavy' SG ~ [ə] *trymion* 'heavy' PL from Proto-Brythonic **trumm* (Schrijver 1995: 25-26, Hannahs 2013: 57). Languages from Asia offer some relevant examples as well. Old Iranian and Proto-Semitic *ĭ* and *ŭ* have yielded stressed schwa, respectively, in Pashto in open syllables ([ɣaˈnəm] from **gantú-ma* 'wheat' M PL, [ˈʃəga] **sikā* 'sand'; Cheung 2011: 179, 182) and in Central Cushitic and Gəʿəz (Appleyard 2011: 43, Weninger 2011: 1128). It has also been contended that Old Tibetan high front and back vowels have given rise to stressed schwa in Zhongu Tibetan (Sun 2003: 791).

The substitution of short high vowels by stressed schwa has also occurred in Late Modern English: somewhere in the 17th-18th c., /ɪ/ (*dirt, bird*), /ʊ/ (*turn, nurse*) and /ɛ/ (*earth, term*) merged into stressed [ɜː] when followed by tautosyllabic /r/ (Lass 1999: 113, Hickey 2012). In contemporary English dialects, stressed schwa may be the realization of /ɪ/ as in *kit* in New Zealand and Southern African English, of /ʊ/ as in *foot* in Northern England near-RP, and of unrounded back /ʌ/ as in *strut* in Northern England near-RP and in the south of the United States (Wells 1982: 352-353, 536, 606, 612).

As some of the examples just cited reveal, whenever only one of the two short high vowels has shifted to schwa historically, it happens to be the high front rather than the high back cognate, presumably because schwa is more similar articulatorily to /ɪ/ than to /ʊ/ (i.e. schwa and /ɪ/ are unrounded vowels while the production of /ʊ/ involves some lip rounding). In Afrikaans stressed [ə] has replaced earlier /ɪ/ (*pit* 'wick', *bid* 'pray'; Swanepoel 1927: 23, Prinsloo 2000: 54), and in Francoprovençal /i/ may have changed to [ə] in historically checked syllables, where vowels are shorter than in open syllables (Vaudois [ˈvəla] VĪLLA 'town', [ˈrətso] *RICCU 'rich'; Stricker 1921: 42, Gauchat *et al.* 1925). In this connection, the symbol **ɨ*, which corresponds to a high central unrounded vowel, has often been used to denote the source of schwa in stressed or prominent syllables in linguistic reconstruction studies. The sound change **ɨ* > [ə] appears to have proceeded from Proto-Uralic to Proto-Samoyed as revealed by Selkup, and from Proto-Zyryan to Komi (Sammallahti 1988: 484, 495, 533). Also relevant to the point being made are some Chadic languages (Margi [pətʃi] from Proto-Margi **pɨtsi* 'sun'; Gravina 2014: 178, 337) and the Tai dialects, Lungchow and Po-ai, where Proto-Tai short **ɨ* yielded [ə] and the long cognate **ɨː* resulted in [ɯː] in open syllables and in [əː] in closed syllables, as exemplified by the Lungchow lexical items [mək] 'ink', [lɯː] 'day after tomorrow' and [kən] 'night' (Li 1977: 11, 264-265). Standard Bulgarian appears to be an exception in this regard (see above) and so is Tatar, where stressed schwa is considered to derive from the high back unrounded vowel *ɯ (Comrie 1997: 901).

2.2. Mid front vowels

Another source of stressed schwa is the mid high front vowel /e/, which is also relatively short compared to mid low vowels and /a/. In partial resemblance to the source pair [ɪ]/[ʊ] (see section 2.1), a greater degree of phonetic similarity implemented in terms of tongue fronting and rounding may explain why stressed schwa may derive from /e/ rather than from /o/.

In Balearic Catalan and dialects of Occitan such as that of Basse Auvergne, Late Latin stressed /e/, which arose through the merging of Classical Latin /eː/ (Ē) and /ɪ/ (Ĭ), has been replaced by schwa highly systematically irrespective of syllable type, word position and length and the articulatory properties of the contextual consonants (Balearic [plə] PLĒNU 'full' M SG, [səp] CĬPPU 'strain', [ˈsəðə] SĒTA 'silk', Vinzelles [plə], [sə], [ˈsəda]; Dauzat 1897: 67-68, Recasens 2019). Also in a wide range of positional and contextual conditions, not only Latin /e/ but also other Latin stressed vowels have shifted to schwa in Gallo, a western French dialect: (/e/) [dɾə(t)] DIRĒCTU 'straight'; (/ɛ/) [pjə] PĔDE 'foot', [lə(t)] LĔCTU 'bed'; (/a/) [pɾə] PRATU 'prairie', [puˈmjə] POMARIU 'apple tree'; (/ɔ/) [nə(t)] NŎCTE 'night' (Chauveau 1984). In dialects of Ladin Rhaeto-Romance and Francoprovençal and from N. Italy, on the other hand, the emergence of stressed schwa from Latin /e/, which may exhibit slight differences in height and fronting depending on dialect, has been strongly determined by segmental shortening in the following circumstances (Gartner 1879, Pellegrini 1954-1955: 312, 316, 392, Parry 1997: 239-240):

(i) In closed syllables, as exemplified by Gardenese [tʃaˈvəl] CAPĬLLU 'hair' M SG, [sək] SĬCCU 'dry' M SG and the suffix -[ət] -ĬTTU, Livinallonghese [frɐʃk] Germanic *FRĬSK 'fresh' M SG, and Piedmontese [ˈsəkːa] SĬCCA 'dry' F SG, [kawˈsət] CALCEU + ĬTTU 'sock'.
(ii) In paroxytones ending in [a] irrespective of whether the stressed vowel occurs in an open or a checked syllable, such as Livinallonghese [ˈtɐla] TĒLA 'cloth', and Piedmontese [spəsːa] SPĬSSA 'thick' F SG and the form [ˈsəkːa] SĬCCA mentioned in point (i) above.

(iii) In Latin proparoxytones, which may have turned into paroxytones after the deletion of posttonic vowels, as exemplified by Livinallonghese [ˈsɐdeʃ] SĒDECIM ‘sixteen’ and Piedmontese [ˈvəsku] EPĬSCOPU ‘bishop’, [ˈvədːe] VĬDERE ‘to see’ and [ˈfəmna] FĒMINA ‘female’ and, thus, in open and checked syllables.

In these particular dialects (though not in the Catalan and Occitan ones referred to above) vowel reduction is associated with vowel shortening whether induced by an increase in the number of segments in syllable-coda position (and thus in closed *vs* open syllables) and in the number of syllables in the word (and thus in proparoxytones vis-à-vis paroxytones and oxytones), or by the presence of word-final [a], which in so far as it happens to often be the longest vowel in vowel systems may cause the stressed vowel to shorten through some sort of compensatory effect. Moreover, as some of the examples just mentioned reveal, vowel shortening and reduction to schwa may be triggered by two factors acting simultaneously, such as vowel placement in checked syllables in paroxytones ending in [a] or in Latin proparoxytones. It seems that the same sound change process /e/ > [ə] may also operate on highly frequent lexical items ([ˈkəlo] *ECCU ĬLLE ‘that one’, [ˈkəto] *ECCU ĬSTE ‘this one’ in Occitan from Prali; Morosi 1890: 334) and in short monosyllables ([mə] MĒ and [tə] TĒ, 1st and 2nd person singular pronouns, [rə] RĒGE ‘king’ in Ligurian from Val di Magra; Restori 1892: 12).

To those Romance dialects we may add Luxembourgish, where stressed schwa has originated from the mid high front end product of West Germanic /i/ and can be regarded as an allophone of /e/ except when occurring before historically velar consonants where [e] is found instead ([kən] *Kënn* ‘chin’, [fəʃ] *Fësch* ‘fish’, [mek] *Méck* ‘fly’; Gilles & Trouvain 2013, Gilles 2014). Moreover, the replacement of /e/ by [ə] in stressed position has also taken place in languages from outside Europe in which stressed schwa is frequently transcribed as back unrounded in spite of being implemented as mid central phonetically. Thus, Proto-Mongolic **e/*eː* evolved into [ə]-[əː], often represented as [ɤ]-[ɤː], in Old Mongolic, as revealed by the occurrence of this short/long vowel pair in the Inner Mongolian languages Chakhar, Baarin and Daghur ([ən], [ənə] **ene* ‘this’, [ər] **ere* ‘man’, [kər] **ker* ‘house’; Tsumagari 2003: 131, Svantesson *et al.* 2005: 157, 161, 164, 180-184); this historical relationship is also in accordance with the realization of /e/ as [ə] in stressed CV syllables in Monguor ([kə] *ge* ‘to do’; Slater 2003: 33). In Korean, **e* yielded stressed schwa or a comparable vowel, which is dated as far back as Early Middle Korean, and has given rise to /ʌ/ which is realized as [ʌ] if short and as [ə] if long in the standard language ([jʌŋ] 'glory', [jəːŋ] 'eternal') and as [ə] in Cheju, where no length distinction occurs (Lee 1999, Cho *et al.* 2001, Lee & Ramsey 2011: 94, 295). A similar case is that of Estonian /ə/ or /ɤ/ (*õ*), which comes from Proto-Finnic **e* in words which had a back vowel in the following syllable (Estonian *võlg*, N. Finnic *velka* 'debt'; Laakso 2001: 183).

Much less often, stressed schwa happens to correspond synchronically to the more open and thus longer mid front low vowel /ɛ/ though, interestingly enough, often next to consonants which may have caused this vowel to raise to mid high front (see section 3.2 in this respect). The vowel /ɛ/ is realized as [ɜ], [ə] before labial and velar consonants and in falling diphthongs with a palatal glide in Eton, a Bantu language from Cameroon ([pɜj] /pɛj/ 'viper' and [ndɜg] /ndɛg/ 'calabash', both words with a high tone; van der Velde 2008: 29), and as [ə] in syllables checked by a coda velar nasal or a glottal stop in Shanghai Chinese, whose vowel system does not have /e/ ([kəŋ] 'root'; Zee & Xu 2003: 133).

2.3. Low and mid back vowels

Stressed schwa may also derive from a low vowel, mostly if short and therefore exhibiting a reduced [ɐ]-like realization and probably front and thus showing a spectral configuration relatively similar to that of schwa. The replacement of a short variant of stressed /a/ by schwa, which parallels the opposite shift /ə/ > [a] (see section 4.1), has taken place in several Slovenian dialects in addition to the reduction of *ĭ* and *ŭ* ([kɾəp] *krap* 'carp'; Petek *et al.* 1996) and in Chechen, where etymological and underlying /aː/ is realized as [a] (Nichols 1997: 945, 949). It also occurred during the transition from Old Hindi to Modern Standard Hindi (Misra 1967: 215) and from Early Iranian to Ossetic ([fiˈdə] 'father' < **pita*; Testen 1997: 724).

The sound change /ɔ/ > [ə], on the other hand, has taken place in Sentani ([mə] 'hand, arm'; Cowan 1965: 4-5, Foley 1986: 54), while in Bulgarian and Macedonian dialects it should be attributed to vowel nasalization and therefore may be considered to have been contextually conditioned (see section 3.2.1).

2.4. Summary

In agreement with our initial hypotheses, the sound change data presented so far reveal that stressed schwa originates mainly from relatively short vowels whether because they are high or mid high, count as short in languages opposing long and short vowels phonemically or because they occur in specific syllable and word positions. Combinations of those factors may also apply. Moreover, the failure of back rounded vowels to shift regularly to schwa may be taken to support the role of spectral similarity in the emergence of stressed schwa from peripheral vowels. In sum, the inception of stressed schwa appears to be associated mostly with segmental duration though also with phonetic similarity, i.e. stressed schwa is expected to derive from short rather than longer vowels, essentially if front.

3. Sound change mechanisms

In principle, those sound change mechanisms dealt with in sections 3.1 and 3.2, i.e. vowel-to-vowel and consonant-to-vowel assimilation, should play an active role in the genesis of stressed schwa, the rationale for this being that coarticulatory effects in articulatory configuration exerted by contextual vowels and consonants on the stressed vowel subjected to change may become categorical and thus be phonologized. Moreover, those contextual effects are expected to occur especially in languages where stressed schwa is not likely to have emerged through segmental shortening induced by factors such as those referred to in section 2.2 and thus, for example, in Catalan and Occitan dialects rather than in Ladin Rhaeto-Romance and Francoprovençal dialects. In other words, context-dependent changes in articulation are expected to become the primary source of stressed vowel centralization whenever the duration dimension is not directly involved in the implementation of this sound change.

3.1. Vowel context effect

It is hypothesized that stressed schwa may have originated through assimilation to instances of unstressed schwa, as suggested by a large number of languages endowed with stressed schwa which also have schwa in unstressed position (whether vowel reduction is still an active process or not), while the reverse does not generally hold. Indeed, a vast majority of the roughly 100 languages and dialects with stressed schwa in their vowel inventory listed in Recasens (2022) allow for the presence of schwa in the two stress positions, the number of languages exhibiting schwa in stressed syllables but not in unstressed ones being relatively small, this group comprising Ngwe and Wolof (Niger-Congo family), some Macedonian dialects but not others (Slavic), Udmurt and perhaps Selkup, where nevertheless stressed and unstressed [ɨ] may co-occur in the same word (Uralic), and Korean, whose phoneme /ʌ/ (or /ə/) may be realized as [ʌ] if short and as [ə] if long (Koreanic). Moreover, as exemplified in Table 1, in languages endowed with schwa in stressed and unstressed position the two schwa types may co-occur in the same word, which may be adduced in support of the vowel-to-vowel assimilation hypothesis.

This prediction faces several problems, however. On the one hand, it is not consistent with the trend for unstressed vowels and mostly schwa to coarticulate with stressed vowels rather than vice versa (Fowler 1981). It may be argued in this respect, though, that in so far as the presence of schwa in stressed syllables is an exceptional event, the genesis of this vowel ought not to conform necessarily to the expected coarticulatory tendency. On the other hand, as pointed out to us by a reviewer, to motivate the vowel assimilation hypothesis it would be desirable to see evidence for historical sound correspondences in which the same vowel quality develops into stressed schwa when adjacent to an unstressed schwa but remains unchanged in the absence of that context. Nevertheless, no direct evidence of this sort seems to be available, i.e. no dialects have been found in which stressed schwa must co-occur with unstressed schwa in the same word, perhaps because stressed schwa has spread rapidly to other contexts, as exemplified by /ow/ and /uw/ fronting in American English dialects, which started out after coronals and came about later after non-coronals (Labov *et al.* 2006, chapter 12). Another controversial aspect is the relative chronology of the emergence of unstressed schwa and stressed schwa in a given language or dialect. Regarding this issue, for stressed schwa to originate through vowel-to-vowel assimilation in words which had unstressed schwa in them, schwa ought to have emerged historically in unstressed syllables before it occurred in stressed syllables. In support of this possibility one may adduce that vowel reduction applies typically in unstressed syllables, and also that precedence of schwa in unstressed over stressed position is expected to have been at work in those dialects where the replacement of stressed /e/ by [ə] is not primarily associated with segmental shortening (see section 2.2). Additional evidence could come from dialect scenarios of a given language where stressed schwa may be found in areas where unstressed schwa is available but not in other areas where unstressed schwa is absent, i.e. in Western *vs* Eastern Landais Gascon (Millardet 1910) and in the Balearic *vs* Central dialects of Catalan.

3.2. Consonantal effect

Changes in articulatory configuration during the production of stressed vowels as a function of contextual consonants result in coarticulated vowel realizations which may be categorized as schwa by listeners.

Language families	Languages/dialects
Albanian	Albanian
Amazonian	Mosetén
Australian	C. Arrernte
Austro-Asiatic	Khmer
Austronesian	Budai Rukai
	Karo Batak
	C. Paiwan
Bantu	Nen
Caucasian	Chechen
	Kabardian
Celtic	Scottish Gaelic
Chadic	Sharwa
Germanic	Luxembourgish
Indo-Aryan	Gujarati
	Sinhalese
Iranian	Digor Ossetic
	Kurdish
	Pashto
Koreanic	Cheju
Mongolic	Bonan
	Daghur
Niger-Congo	Ndut
N. American Indian	Squamish
	Halkomelem
	Babine
	Saanich
	Lillooet

Table 1. Languages and dialects showing schwa in stressed and unstressed syllables together with lexical items exemplifying the co-occurrence of the two vowel types within the same word.

Examples
[ˈnənə] 'mother', [ˈkəmbə] 'leg', [ˈəndər] 'dream', [ˈrəɾə] 'sand'
[ˈpəpəx] 'father in law', [ˈdərəʔ] 'tree' (Sakel 2004: 20, 33)
[əˈkʷəʈ] 'smoke' , [əˈmən] 'vegetable food' (Breen & Dobson 2005)
[təːˈkə] 'work' [ʔəˈʋəj] 'what?' (Donley 2020: 39)
[ˈəbəɭə] 'smoke', [ˈəːnə] 'all right' (Chen 2006: 198, 239)
[dəhˈkən] 'to compress', [ərkəˈtə] 'to sulk' (Adelaar 1981)
[ɭəˈsəq] 'tear', [rəˈməŋəz] 'to ambush' (Chen 2006: 65, 70)
[bəɾəm] 'spit', [kənəm] 'come!' (Evans & Miller 2016)
[ˈbərzə] 'dog's name', [ˈdwəttəɣ] 'friend' (Nichols 1997: 949)
[fəˈzəʒə] 'old woman', [bəˈsəm] 'host' (Colarusso 1992: 42, Gordon & Applebaum 2010)
[ˈbəðəm] 'yeast' (Hall 2003: 109)
[ləmən] 'border', [tsəkən] 'to collect' (Gravina 2014: 137)
[ˈzətsən] 'to sit', [ˈtʀəpələn] 'to trip' (Gilles 2014)
[səkhət] 'strong', [nəgər] 'city' (Cardona & Suthar 2003: 724-725)
[kəɾə] 'do' (Gair 2003: 860)
[əpˈpət] 'all', [xəsˈkə] 'bearing' (Testen 1997: 712)
[ˈnəkə] 'if he does not do', [ˈhəjə] 'there is' (McCarus 1958: 15, 20)
[ˈnəhə] 'nine', [ˈʒəbə] 'tongue' (Robson & Tegey 2009: 724)
[tʰəˈləttʃə] 'to dust' (Cho *et al.* 2001)
[ələŋ] 'many', [tərəŋgə] 'a head' (Chuluu 1994: 2-3)
[əntʷəkʷ] 'egg', [xətʃə] 'when' (Svantesson *et al.* 2005: 165, 170)
[ˈɓəːwə] 'the people', [ˈjəkkə] 'the puppy' (Morgan 1996: 20, 39)
[wəˈxəs] 'frog' (Dyck 2004: 378)
[ˈxəxəl] 'frost' (Galloway 1977: 124)
[dəlˈkwəs] 'he is coughing' (Hargus 2005: 400)
[ˈŋəsənˀ] 'louse' (Montler 2005: 19)
[ˈsqəqʼjəxʷ] 'boy', [ˈpəlkʼəqʷ] 'to turn around' (Eijk 1997: 12, 17)

continued

Papuan	Sentani
	E. Sepik
	Yessan-Mayo
Romance	Majorcan Catalan
	European Portuguese
	Gardenese Ladin
	W. Landais Gascon
	Auvergnat Occitan
	Romanian
Semitic	Amharic
Sino-Tibetan	Chantyal
	Mandarin Chinese
Slavic	Bulgarian
	Kashubian
	Slovene
Turkic	Tatar
Uralic	Cheremis
	Moksha

This section deals with those consonantal environments which cause these assimilatory changes to occur.

3.2.1. Vowel nasalization

A source of stressed vowel centralization is vowel nasalization, which may be induced by a nasal consonant following the target vowel mostly if placed in syllable-final position.

The target segment may be a low vowel in this case. The raising process [ã] > [ə] has taken place in several Romance languages: in dialectal regions of Rhaeto-Romance such as Surselvan ([cəwn] CANE 'dog'; Haiman 1988: 354) and Livinallonghese Ladin ([məŋ] MANU 'hand', [səŋk] 'blood'; Sampson 1999: 230), and in dialects from N. Italy such as Romagnol ([kə̃ː] CANE; Hajek 1997: 274); in Medieval Portuguese ([kɐ̃w̃] CANE) and more modernly in European Portuguese ([ˈkɐmɐ] 'bed', [ˈmɐɲɐ] 'astuteness'; Mateus & d'Andrade 2000: 19); and in Old Romanian, after which [ə̃] raised to [ɨ] ([kɨmp] CAMPU 'field'; Sampson

[əˈdəm] ‘see you’, [əˈləj] ‘speak!’ (Cowan 1965: 9)
[ˈgəɲər] ‘later’, [nəˈkər] ‘cool’ (Aikhenvald 2008: 41)
[ˈtʰəmnə] ‘shoulder’, [ˈwərə] ‘tomorrow’ (Foreman & Marten 1973: 87-88)
[kəˈzətə] ‘little house’, [ˈpəɾə] ‘pear’
[ˈtɐʎɐ] ‘roof-tile’, [ˈsɐɲɐ] ‘fury’ (Mateus & d’Andrade 2000: 19-20)
[awˈɾəjəs] ‘ear’ PL, [nəˈvəta] ‘heavy snowfall’ (Bammesberger 1974)
[ˈbœdə] ‘to see’, [ənˈtœj] ‘full’ M SG (Millardet 1910)
[ˈfədzə] ‘liver’ (Dauzat 1897: 68)
[kəˈɾəɾʲ] ‘paths’, [ˈməturə] ‘broom’ (Chitoran 2002)
[ˈnəgə] ‘tomorrow’, [ˈkəsəl] ‘charcoal’ (Leslau 1995: 32, 284)
[ˈəncəl] ‘province’, [ˈɦiəcə] ‘that (demonstrative)’ (Noonan 2003: 317, 322)
[wan ɹəŋ] ‘evening’, [nəŋ kən] ‘capable’ (Lin 2007: 162)
[grəˈdət] ‘the city’, [gləˈsjə] ‘I prepare’ (Klagstad 1958: 46, 48)
[ˈməʃləc] ‘to think’ (Topolińska 1974: 184)
[ˈtəmən] ‘dark’, [ˈməsə] ‘meat’ (Lencek 1982: 161, Greenberg 2000: 168)
[kˤərˈfəkˤ] ‘eye-lashes’ (Poppe 1961: 12)
[ˈtələzen] ‘moon’s’, [ˈkəzet] ‘yet’ (Sebeok 1961: 9, 96)
[ˈkərʲdʲəms] ‘to keep’, [ˈsərməms] ‘to crease’ (Aasmäe *et al.* 2013: 19)

1999: 322). In the Balkans region, on the other hand, stressed schwa may be traced back to /ã/ in Tosk Albanian (Gheg [zɑ̃] ~ Tosk [zə] **zan* ‘voice’; Maynard 2003: 83), and to /ɔ̃/ in Bulgarian (Vaillant 1950: 152) and in dialects of Macedonian ([pət] ‘road’ from Proto-Slavic **pɔtь* in Debar and Seres/Nevrokop; Friedman 2001: 7). Additional evidence for the replacement of a nasalized low vowel by schwa before a nasal consonant comes from Old Avestan short **a* (Skjaervø 2006: 23), from Haida, an indigenous language from North America, and from Guelavía Zapotec spoken in Mexico (Beddor 1983: 37).

The mid front vowel /ẽ/ may also be subjected to centralization in Piedmontese (Roaschia [ˈləŋga] LĬNGUA ‘tongue’, [pjəŋ] PLĒNU ‘full’ M SG; Salvioni 1907: 526), Old Romanian after which [ə̃] shifted to [ɨ] ([fɨn] FĒNU ‘hay’; Lausberg 1965: 275) and Tosk Albanian (Gheg [pẽ] ~ Tosk [pə] **pen* ‘thread’; Maynard 2003: 83). In Gardenese Ladin, after having raised to a mid high front vowel, nasalized /ɛ̃/ was able to join /e/ in becoming [ə] ([təmp] TĔMPU 'time', [dənt] DĔNTE 'tooth'; Gartner 1879 and section 2.2) and the same string of sound changes occurred in Francoprovençal from Noasca in Valle dell'Orco ([vən] VĔNTU 'wind', [sən] CĔNTU 'one hundred'; Zörner 2003: 47).

The replacement of nasalized mid front and low vowels by schwa cannot be attributed to segmental shortening since nasalized vowels are longer, not shorter, than oral ones (Sampson 1999: 23-24). As argued for by Beddor (1983), the most plausible explanation is to be found in spectral changes induced by velopharyngeal coupling and thus the addition of nasal and oronasal formants to the oral vowel spectrum. Regarding /a/, for example, both F1 and the 100-1100 Hz frequency band centroid are lower in the case of the nasalized *vs* oral cognate, which accounts for why listeners may hear the nasalized low vowel as higher than its oral counterpart (Beddor 1983: 139, 146). Analogous spectral changes induced by the nasalization characteristic could account for the raising of /ɛ̃/ to [ẽ] in the Gardenese Ladin examples given above.

3.2.2. Labial consonants

Mid high front /e/ has shifted to [ə] after a labial consonant in Romanian ([pəɾ] PĬLU 'hair'; Lausberg 1965: 275) and to [œ] in Bormio in Northern Lombardy ([bœɾ] BĬBERE 'to drink'; Meyer-Lübke 1974, 1: 120). In the English dialect of East Anglia, on the other hand, the change /e/ > [ɜ], [ʌ] may also operate after a labial and before a glottal stop in the penultimate syllable (*better*, *metal*; Wells 1982: 340). Labial assimilation appears to have also triggered the raising of short **a* to [ə] (also to *o*) in Old Avestan (Skjaervø 2006: 52).

The replacement of /e/ by schwa after a labial stop consonant could result from the lowering of the vowel formant frequencies as the lips remain close to each other to a greater or lesser extent and for a variable period of time after the consonant release (see Fant 1960 for the lowering effect of lip closing and rounding on all formant frequencies). This sound change occurs often in the word syllable-initial position, where the stop burst becomes most prominent. A progressive vowel assimilation induced by a prevocalic labial consonant accounts for other changes such as the backing and rounding of unstressed *e* into *o* (Leonese [posˈtaɲes] for Spanish [pesˈtaɲas] 'eyelashes') and the insertion of the glide [w] between a labial or labiodental consonant and the following vowel (Judeo-Spanish [ˈpwaðɾe] PATRE 'father', Southern Portuguese [ˈvwaso] VASU 'glass') (Recasens 2014: 45, 86).

3.2.3. Back lingual consonants

Stressed front vowels may retract to schwa when occurring next to lingual consonants whose production involves the formation of a closure or constriction at the back of the vocal tract, or else a front place of articulation simultaneously with a more or less retracted tongue body.

The role of dorsovelar consonants in the retraction of mid high front /e/ to schwa in stressed position is doubtful since, at least in VC sequences, velars are realized as postpalatal in the context of front vowels and consequently ought to cause those vowels to stay palatal (see in section 2.2 the presence of [e] instead of schwa before a velar consonant in Luxembourgish). In any case, there are instances of the replacement of stressed /e/ by [ə] in the velar consonant context condition. In Scottish Gaelic dialects this change may be found before /g/ ([pək] *beag* 'small'; Ó Maolalaigh 1997, 1: 291), and in Monguor schwa happens to be an allophone of /e/ after velars ([kʰən] *ken* 'who'; Georg 2003: 289). In Vlax Romani, on the other hand, the change /e/ > [ə] has taken place next to velars and uvular /ʀ/ in addition to when adjacent to /s/ and /ʃ/ ([kʰər] 'house', [ʃəl] 'hundred'; Matras 2002: 59, 224).

The apicoalveolar rhotic and the dark alveolar lateral may also cause stressed /e/ to shift to schwa. Thus, the changes /e, ɛ/ > [ə] and /i/ > [ɨ] have operated after a trill in Romanian ([rəw] *rău* RĔU 'bad', [ˈrɨde] *râde* RĪDET '(s)he laughs'; Lausberg 1965: 268). The progressive effect of the rhotic appears to occur in conjunction with vowel shortening if it is part of a syllable-onset consonant cluster, as exemplified by forms from Gallo ([dɾə] DIRĒCTU 'straight' M SG, [kɾə] CRŬCE 'cross'; Chauveau 1984: 80) and Scottish Gaelic dialects ([kɾʲək] *creag* 'rock', [kɾʲətʲ] *creid* 'to believe', [gɾʲəs] *greas* 'to hurry'; Ó Maolalaigh 1997, 1: 291-294). On the other hand, in East Anglia, /e/ is realized as [ɜ] or [ʌ] before syllable-final /l/ (*tell, bell*; Wells 1982: 340). Generally speaking, vowel backing and lowering in the cases just reviewed is associated with some tongue blade and predorsum lowering and tongue postdorsum retraction during the formation of the apical constriction for the rhotic, mostly if implemented as a trill or a trill-like articulation, and for dark /l/ too (see Recasens 2014 for details). Moreover, as the above examples show, while the assimilatory action of the alveolar lateral is mainly regressive and associated with the anticipation of the tongue body activity before the tongue tip is raised for the formation of the apical closure, that of the alveolar trill may also be progressive and related presumably to the strict manner of articulatory requirements involved in the performance of the apical trilling mechanism.

A related change is the perceptual integration as stressed schwa of an intrusive vowel in [Cr̩] and [Cl̩] sequences, thus yielding [Cər] and [Cəl] (see Roach & Miller 1991 for the intrusion of unstressed schwa in such consonantal sequences in English words like *bottle* and *button*). This change has taken place in the two cluster structures in Macedonian dialects ([kərv] for [kr̩v] 'blood', [vəlk] for [vl̩k] 'wolf'; Friedman 1993: 301), and in clusters with a rhotic C2 in the Chakavian dialect of Croatian ([ˈtərste] *Trste* 'Trieste'; Kalsbeek 1998: 35) and in Piedmontese ([ˈtərsa] 'braid' – cf. Italian *treccia* –, [ˈkərpu] CREPO 'I crack'; Miola 2013: 57).

Another relevant vowel assimilatory process is associated with retroflex consonants. The effect of a syllable-final retroflex rhotic may account for the regressive centralization of /ɪ ɛ ʊ/ into [ə] in Middle English (*bird*, *fern*, *nurse*; Hickey 2012) while in Monguor stressed [ɜ] happens to be an allophone of /e/ after (retroflex) /r/ (Georg 2003: 289, Slater 2003: 26, 30). An interesting case is that of the Dravidian languages Kodagu, Kurumba, Toda and Irula, which underwent centralization of long and short /i/ and /e/ into stressed schwa before retroflex dentoalveolars and possibly the alveolar rhotic in root syllables, in particular when the target vowel was not preceded by a palatal or labial consonant at least in Kodagu (Krishnamurti 2003: 51, 112-113). Vowel rhotacization results from two main anticipatory mechanisms involved in the production of the retroflex rhotic, i.e. tongue body bunching or else backward curving of the tongue tip, which may cause F3 of the preceding vowel to lower. A more posterior apical constriction than for non-retroflex consonants is available for retroflexes in general, while the relationship between differences in primary constriction location and tongue body backing degree between retroflex and non-retroflex consonants awaits further investigation (see Hamann 2003, Flemming 2003 and more recently Kochetov *et al.* 2014 regarding this point).

3.2.4. Palatal consonants

The transformation of stressed /e/ to schwa may also take place next to palatal or palatalized consonants (see in this respect Scottish Gaelic forms such as [krʲətʲ] *creid* 'to believe' in section 3.2.3). It may be that this particular context-dependent sound change results from a compensatory vowel shortening effect induced by palatal consonants, which tend to be longer than dentals and alveolars in line with differences in motion speed between the corresponding primary lingual articulators, i.e. the tongue (pre)dorsum for palatals and the tongue tip and blade for dentoalveolars (see, for example, differences in acoustic duration for [ɲ] > [n] in French in Belasco 1953). Moreover, the replacement of /e/ by schwa in this contextual condition appears to also be dissimilatory in so far as it involves the retraction of the stressed vowel while palatal consonants are front lingual articulations.

Relevant examples of stressed /e/ retraction into schwa next to palatal consonants come from the Romance languages. In the Lisbon-based variety of European Portuguese, /e/ has been replaced by a central vowel, which is represented by [ɐ], before all palatals including /j/ ([ˈtɐʎɐ] *telha* 'tile', [lɐj] *lei* 'law'; Mateus & d'Andrade 2000: 19). As pointed out next, in other dialectal scenarios, the sound change of interest has taken place before a subset of palatal consonants.

(i) In Francoprovençal and Occitan dialects and in addition to other possible factors (see section 2.2), postvocalic /ʎ/ and /ɲ/ may have been involved in the change [e] > [ə] whether the mid front high vowel corresponds to source /e/ or to a lowered realization of source /i/ generated through regressive dissimilation: Valaisan from Vionnaz [aˈvəðə] APĬCULA 'bee' and Val d'Illiez [ˈpəɲə] PĔCTINAT '(s)he combs', [ˈfəðə] FĪLIA 'daugther', [ˈvəɲə] VĪNEA 'vineyard'; Génevois from Certoux [øˈɾəʎ] AURĬCULA 'ear'; and Occitan from Prali [aˈbəʎo] 'bee', [ˈnsəɲu] 'I teach', 1st person singular present indicative of INSĒGNARE (Gilliéron 1880: 32, Morosi 1890: 334, Fankhauser 1910: 240, 266, Keller 1919: 27-28). In Ain from Vaux-en-Bugey, the change in question may apply not only before a palatal consonant but also after it ([mɔˈnəja] MONĒTA 'coin', [ɔˈɾəʎi] AURĬCULA, [paˈjə] PACARE 'to pay', [bənəˈjə] BENEDĪCERE 'to bless'; Duraffour 1930: 11).

(ii) The centralization of /e/ into schwa may occur exclusively before /j/. This is the case for Romansh from Disentis where [əj] is the regular realization of /e/ in open syllables, as in [nəjf] NĬVE 'snow' and [səjt] SĬTE 'thirst', and may also have emerged through dissimilatory lowering from the sequence [ij], as in [ˈʃpəjə] SPĪCA 'spike' (Huonder 1900: 468, 486). Interestingly enough, in the Francoprovençal dialect of Noasca in Valle dell'Orco /i/ is implemented as [əj] in open syllables ([aˈvrəjl] APRĪLE 'April', [nəj] NĪDU 'nest'), while /e/ is realized as [aj] in open syllables though as [əj] if preceded historically by a palatal consonant ([saj] SĬTE 'thirst', [ˈsəjna] CĒNA 'supper') (Zörner 2003: 44-46). These cases may also result from centralization of the diphthong nucleus when shortened and articulatory reduced. Thus, /aj/ may be centralized into [ɐj], [əj] in certain American English varieties (Kilbury 1983), and instances of stressed schwa occurring in open syllables in southeastern Italy appear to have emerged from falling diphthongs as well: /a/ > [ɛe̯], [ɛə̯] > [ə] (San Valentino in Abruzzo Citeriore [ˈtrəːvə] TRABE 'beam'; Passino & Pescarini 2019); mid vowels > [əj], [ɜj] > [ə] (Montrone in Puglia [ˈpəːtə] PEDE 'foot', [ˈvɜːʃə] VOCE 'voice'; Manzari 2017-2018).

3.2.5. Summary

It has been argued that stressed schwa may arise through assimilation to co-occurring unstressed schwa in the same word since: stressed schwa is a fairly uncommon sound in the world's languages; languages endowed with stressed schwa also have schwa in unstressed position while the reverse does not generally hold. Vowel centralization into schwa may also be associated with certain articulatory characteristics induced by the contextual consonants, namely nasalization, lip closing and tongue dorsum retraction. Regarding vowel nasalization, the cause is acoustic-perceptual, i.e. /e/ and /a/ may be replaced by schwa due to changes in the vowel spectrum. Albeit being different articulatorily, consonant-to-vowel coarticulatory effects involving labialization and tongue body retraction may yield schwa out of /e/ through a decrease in the vowel F2 frequency. Unlike the three previous cases, the motivation for the emergence of stressed schwa from /e/ in the adjacency of palatal consonants appears to be dissimilatory instead of assimilatory and associated with vowel shortening as well.

4. Replacement by other vowels

Another prediction tested in this study is that while both segmental shortening and spectral similarity ought to play an important role in the genesis of stressed schwa, only spectral similarity is expected to intervene in the replacement of stressed schwa by other vowels in vowel systems which do not oppose long and short vowels phonologically. Thus, once stressed schwa has become fully integrated in the vowel system of a particular language, its replacement by another stressed vowel ought to be tied to vowel quality rather than to vowel duration since vowel duration is not an essential characteristic of peripheral vowels in the vowel systems under consideration. In languages where vowel length is distinctive schwa is expected to give rise to short vowels of similar quality.

Given these two general predictions, the F2 frequency data for vowels provided in section 2 suggest more specific trends in sound change. Regarding the vowel source issue, while /e/ (also /ɪ/) should be prone to shift to schwa because of its relative short duration and unroundedness, it may not arise easily from stressed schwa since the spectral characteristics of these two vowels are quite far apart from each other. Stressed schwa is expected to be replaced by the spectrally similar low and mid low vowels (mostly /ɛ/) rather than by high or mid high vowels. The replacement of unstressed schwa by other vowels, which will also be referred to briefly, should conform essentially to the same spectral similarity principle that applies in the case of stressed schwa and ought to give rise mostly to [a] since the mid low front vowel [ɛ] is not prone to occur in unstressed syllables. Moreover, in so far as schwa turns out to be more similar to /ɛ/ than to /ɔ/ acoustically as well as articulatorily, the substitution of stressed schwa by /ɔ/ in sound change could be a plausible option only when it approaches /ʌ/ or /ɤ/ through an increase in postdorso-pharyngeal constriction degree whether cross-contextually or in specific contextual environments. In section 4.3, the feasibility of these potential vowel outcomes of stressed schwa will be evaluated in light of results from a perceptual identification test carried out with excerpts of this vowel embedded in different consonantal environments using as perceptual stimuli productions of stressed schwa by speakers of Majorcan Catalan. The reason for using consonants of different places of articulation in the identification test was to find out whether stressed schwa may be categorized as one vowel or another depending on context and thus if contextual factors are involved in this sound change.

4.1. Low vowels

Stressed schwa is prone to replacement by a low vowel. The change into [a] of /ə/ derived from the Proto-Slavic jers *ĭ* and *ŭ* or of other origins has occurred in Serbo-Croatian ([san] 'dream' and [daːn] 'day', with a falling tone), in Eastern and Western Macedonian during the 13th-14th centuries (Koneski 1983: 65), and in Central and South Western Slovene dialects ([daːn] 'day' derived from [dəːn]; Lencek 1982: 62, 104, Sussex & Cubberley 2006: 113-114). In Romance, the stressed mid central vowel may exhibit lower realizations in Ladin and dialects from N. Italy, which may lead to its replacement by a low vowel, such as [ɐ], [a] in Badiotto (Craffonara 1977: 95, Salvi 1997: 287, 2016: 156-157) and [a] in Piedmonese from Turin and Valsesia (Spoerri 1918: 399, Clivio 2002: 160). Regarding the fate of stressed schwa in language families outside Europe, Proto-Austronesian **a* and **ə* appear to have merged into /a/ in Makassar and also in Minangkabau in the last syllable of the word (Adelaar 2005: 208, Jukes 2005: 650-651), and there is an unclear difference between /ə/ and /a/ in Marathi (Pandharipande 2003: 790).

Schwa is often replaced by [a] via [ɐ] also in unstressed position, as in present-day Central Catalan spoken in the Barcelona region and before stress in dialectal zones of Romanian (Nandris 1963: 50-51). The shift of unstressed schwa to a low vowel may be restricted to specific morpheme, word or sentence positions: there is /ə/ > [a] syllable-finally before a pause in tone languages of the Mofu Chadic group (Gravina

2014: 101-102) and /ə/ > [a], [æ] utterance-finally in Moksha (Raun 1988: 98), while in Upper Chehalis the stressed schwa nucleus of triconsonantal roots becomes a low vowel in open syllables when stress moves to the right (Kinkade 1998: 202-203).

4.2. Mid low vowels

Stressed schwa may also shift to a mid low vowel mostly but not only if front, whether unrounded or rounded. This vowel may be [ɛ] and dialectally [œ] in Afrikaans ([ˈsɛmpəl] *simple*, [vɛ̃ːs] *wins*; Swanepoel 1927: 26). In Kurdish dialects, /ə/ has three allophones [ɛ], [æ] and [ə] which may occur in free variation ([gɛrm], [gærm], [gərm] 'hot'), with the two former vowel realizations occurring typically in stressed syllables and [ə] mostly in unstressed syllables (McCarus 1958: 15; Asadpour & Mohammadi 2014: 108).

Turning now to the Romance languages, schwa has been replaced by [ɛ] in Balearic Catalan-speaking localities, and one is tempted to see this and other mid low vowel qualities derived from /e/ as having been issued from stressed schwa mostly in Ladin and N. Italy:

[ɛ] in Marebbano and Valsesia (Spoerri 1918: 399, Salvi 1997: 287);
[æ] in Gardenese ([sæk] SĬCCU 'dry' M SG; Salvi 2016: 156-157);
[œ] in Val Rendena in Trentino ([lœɲ] LĬGNU 'wood'; Zamboni 1990), Valsesia in Piedmont (Spoerri 1918: 399) and Western Landais Gascon ([pœʃ] PĬSCE 'fish'; Rohlfs 1970: 119);
[ɔ] in Piedmontese from Ossola and Novara and in Emilian from Piacenza (Ossola [frɔtʃ] FRĬGIDU 'cold' M, Piacenza [sɔk] 'dry' M; Zamboni 1990);
[ʌ], [ɑ] in Livinallonghese ([sʌk], [sɑk] 'dry' M SG; Salvi 1997: 287, 2016: 157).

It is less obvious whether, in other dialectal areas of N. Italy, Latin /e/ in checked syllables shifted to schwa before becoming [ɛ] (Parmigiano, Pavese, Romagnol; Gorra 1892: 373, Meyer-Lübke 1974: 123) or [a] (Bolognese [kuˈmatːa] COMĒTA 'kite', Modenese [strɑtː] STRĬCTU 'narrow' M SG; Zamboni 1990), or else there was simply a direct change /e/ > [ɛ], [a].

Unlike the replacement by [a] (see section 4.1), unstressed schwa is not expected to shift to [ɛ] since, among mid front vowels, [e] rather than [ɛ] is likely to occur in unstressed syllables.

4.3. Perceptual identification test

Data presented in sections 4.1 and 4.2 indicate that stressed schwa may be replaced mostly by mid low front and low vowels, and thus [ɛ]- and [a]-like phonetic segments, and much less so by other mid low vowels such as [ɔ]. In order to look for experimental evidence in support of the replacement of stressed schwa by all these vowels, the present section reports results from a perceptual identification test also seeking to determine whether the specific vowel outcome of this sound change depends on consonantal context.

4.3.1. Perceptual stimuli

The perceptual identification test was carried out using as stimuli a subset of stressed schwa productions by five male Majorcan Catalan speakers recorded in 2005 and analysed acoustically in Recasens & Espinosa (2006). F1 and F2 vowel frequencies were obtained from meaningful words in which stressed schwa appeared next to consonants differing in place of articulation: labials ([ˈpəbɾə] *pebre* 'pepper'), dark /l/ ([ˈtələ] *tela* 'cloth'), other dentoalveolars ([pətiˈtətə] *petiteta* 'very small' F SG) and palatals ([ʎəj] *llei* 'law'). These contextual conditions (also referred to as **LAB**, **/l/**, **DA** and **PAL** below) were chosen keeping in mind that schwa is strongly affected by the coarticulatory effects associated with the adjacent consonants. As expected, the analysis results showed that F2 for stressed schwa lowers with regard to the prototypical 1500 Hz frequency when the tongue body lowers and retracts next to dark /l/ and there is some lip closing induced by a contextual labial consonant (and thus in words like [ˈtələ] and [ˈpəbɾə]), and increases with respect to that prototypical F2 frequency when the tongue body is fronted and raised next to palatal consonants and, to a lesser extent, next to dentoalveolars such as /t/ involving no active tongue body lowering and backing (as in [ʎəj] and [pətiˈtətə]).

One vowel excerpt for each speaker and each consonantal context was selected for the perceptual identification test, which amounted to 20 different vowel tokens overall (4 contextual consonants × 5 speakers). The criterion for choosing specific vowel items for the four consonant places of articulation was that their F1 and F2 had to be maximally contrastive. The vowel excerpts, which included the entire vowel except for its very edges bordering the adjacent consonants in order to avoid possible odd frequency characteristics, were lengthened by doubling them so that they were not too short to be appropriately identified by listeners in view of the fact that, as pointed out in section 1, even if stressed, schwa is often shorter than low and other mid vowels. Indeed, according to Recasens & Espinosa (2006), duration data for all Majorcan Catalan vowel phonemes /i e ɛ a ə ɔ o u/ averaged across the five speakers and the four contextual conditions reveal that stressed schwa (117.2 ms, standard deviation = 21 ms) is as short as the high vowels [i]

(108.1 ms) and [u] (124.9 ms) and definitely shorter than all the other system vowels, i.e. [e] (133.9 ms), [ɛ] (160.2 ms), [a] (152.1 ms), [ɔ] (159.6 ms) and [o] (139.4 ms). The vowel excerpts were doubled by splicing two equal vowel portions using the KayPENTAX Multi-Speech analysis program, after which those spectral discontinuities which were judged to cause the vowel to sound unnatural were eliminated by removing one or more pitch pulses placed at the juncture between their two halves.

4.3.2. Stimulus presentation procedure

The perceptual identification test included four tokens of each vowel item and therefore 80 stimuli overall. The stimuli were randomized and separated by a 5 ms interstimulus silence which was rendered twice as long every ten stimuli and, thus, between stimuli 10 and 11, 20 and 21 and so on. The 80 stimuli were presented in isolation for identification to 15 male and female Central Catalan-speaking university academics of about 40-65 years of age who were teaching courses in linguistics (twelve participants) or literature (three participants) at the Universitat Autònoma de Barcelona or at the Universitat de Barcelona and were acquainted with schwa in so far as this vowel happens to be the systematic unstressed allophone of /e/, /ɛ/ and /a/ in their dialect. While both of these Catalan dialects, i.e. Majorcan and Central, have schwa in unstressed position, only in the former dialect does the mid central vowel appear in stressed syllables; thus, Majorcan Catalan [ʎəj], [ˈpəbɾə], [pətiˈtətə] and [ˈtələ] are pronounced as [ʎej], [ˈpɛβɾə], [pətiˈtɛtə] and [ˈtɛlə] in Central Catalan. As to the remaining vowel phonemes, the two dialects share the same seven-vowel inventory /i e ɛ a ɔ o u/.

The test was run by means of the PowerPoint program on a portable PC in quiet room conditions. Subjects were told that they would hear several Catalan vowels and were asked to identify them as any of the eight vowels /i e ɛ a ə ɔ o u/ by writing the corresponding phonetic symbol on an answer sheet.

4.3.3. Statistical analysis

The vowel identification responses and the vowel production data were evaluated statistically with the SAS 9.4 software (SAS Institute Inc., Cary, NC, USA) with the significance level set at $p < 0.05$. Separate Chi-squared tests were run on the vowel identification percentages for all subjects both across consonant conditions and for each contextual consonant (labial, /l/, dentoalveolar, palatal) so as to determine whether differences between the observed and expected vowel response frequencies were significant or not. Another set of Chi-squared tests were performed on the data for each individual subject in order to find out whether their elicited vowel responses contrasted significantly as a function of consonantal context.

In order to ascertain the extent to which the vowel judgments were consistent with the consonant-to-vowel coarticulatory effects occurring in production, the latter were also subjected to statistical evaluation. Repeated measures ANOVA with contextual consonant as the independent variable were run on the F1 and F2 frequency values for stressed schwa produced by all five Majorcan Catalan speakers. Separate analyses were performed on the formant frequencies for the stimuli which had been selected for the perceptual identification test (1 vowel token $\times$ 4 contextual consonants $\times$ 5 speakers = 20 tokens) and on those for the entire dataset reported in Recasens & Espinosa (2006) (7 vowel tokens $\times$ 4 contextual consonants $\times$ 5 speakers = 140 tokens). The significance of formant frequency differences for each pair of contextual consonants was then evaluated statistically by means of Tukey's post-hoc tests.

4.3.4. Results

The cross-subject vowel identification responses yielded a highly significant vowel effect (χ^2 (15) = 911.41, $p < 0.0001$). Vowel-dependent differences were also highly significant for each contextual consonant condition ($p < 0.0001$) and these significant effects were associated with the following vowels: /ə/ in the case of the labial consonant context; /ə/ and /a/ for /l/; /ɛ/ and /ə/ for dentoalveolars; and /ɛ/ for palatal consonants. Therefore, as shown in Figure 1 (top graph), stressed schwa was identified essentially as schwa and /ɛ/ in the LAB and PAL contexts, respectively, while the two other consonantal contexts favoured two vowels each: /ɛ/ and /ə/ for the DA context (which thus resembles the identification results for PAL); and /a/ and /ə/ for the /l/ context (which thus parallels the identification data for LAB). The vowel identification data reported in Figure 1 also reveal that stressed schwa was never heard as /i/ or /u/ and only occasionally as /e/, /ɔ/ or /o/. Moreover, the /ɔ/ and /o/ responses were elicited when the vowel was flanked by labial consonants or /l/ and the /e/ responses were obtained when it occurred next to dentoalveolars or palatals.

The statistical results for the individual participants' data show that subjects were more consistent in identifying the acoustic stimuli when stressed schwa was surrounded by labials (differences among the elicited vowel responses in this contextual condition achieved significance for 12 out of 15 subjects) than by dentoalveolars (six subjects), the other two contextual conditions falling in between (palatals, ten subjects; /l/,

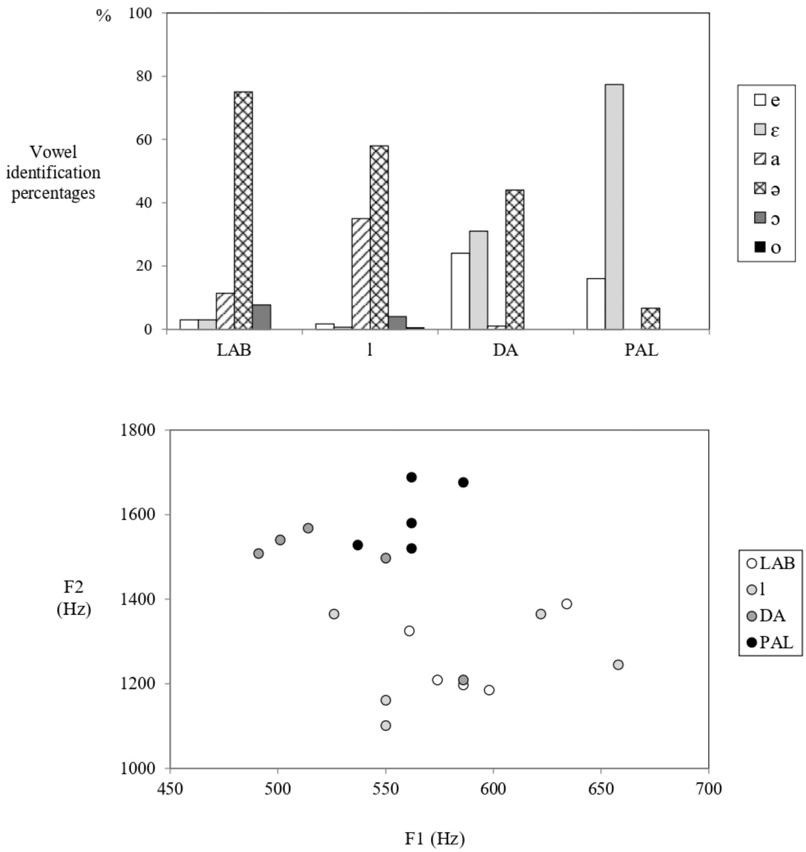

Figure 1. (Top) Vowel identification percentages for productions of Majorcan Catalan stressed schwa in different consonantal environments. (Bottom) F1 and F2 frequency values for the tokens of stressed schwa which were used in the perceptual identification test. The contextual consonants are labelled LAB for labial, /l/ for the alveolar lateral, DA for dentoalveolar and PAL for palatal.

nine subjects). In partial agreement with these results, the vowel identification percentages presented in Table 2 show a more clearly defined picture for the LAB and PAL conditions than for the /l/ and DA ones: about 11-12 participants were inclined to judge the perceptual stimuli as a single vowel about 60% of the time or more in the two former contexts (LAB, PAL), while in the two latter contexts this was the case for only seven (/l/) and three (DA) participants.

		Central Catalan subjects														
Contextual consonants	Vowel identification options	RE	GA	CE	BU	PO	LLO	VM	TCA	ES	LLC	VA	BA	GA	MA	BO
LAB	e	0	0	0	5	0	15	5	0	10	0	10	0	0	0	0
	ɛ	0	0	0	0	0	0	15	0	5	0	10	0	0	15	0
	a	0	15	15	15	55	0	0	15	5	0	40	0	15	0	0
	ə	100	60	80	60	45	85	20	80	55	100	40	100	85	85	100
	ɔ	0	25	5	20	0	0	35	5	25	0	0	0	0	0	0
	o	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0
l	e	0	0	0	0	0	10	10	0	5	0	0	0	0	0	0
	ɛ	0	0	0	0	5	0	0	0	0	5	0	0	0	15	0
	a	30	45	60	35	45	20	0	60	25	20	75	30	45	15	20
	ə	70	45	30	50	50	70	70	40	55	75	25	70	55	85	80
	ɔ	0	10	10	15	0	0	15	0	10	0	0	0	0	0	0
	o	0	0	0	0	0	0	5	0	5	0	0	0	0	0	0
DA	e	25	5	45	5	10	45	40	0	60	5	50	10	30	25	10
	ɛ	40	35	35	40	40	0	40	25	5	0	30	50	35	45	45
	a	0	0	0	0	0	0	0	0	0	0	5	0	10	0	0
	ə	35	60	20	55	50	55	20	75	35	95	15	40	25	30	45
	ɔ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	o	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PAL	e	0	0	10	20	10	30	50	0	40	15	45	5	10	5	0
	ɛ	100	95	90	80	90	50	50	70	40	65	55	95	90	90	100
	a	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ə	0	5	0	0	0	20	0	30	20	20	0	0	0	5	0
	ɔ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	o	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2. Vowel identification percentages elicited by the 15 Central Catalan-speaking participants who took the perceptual test with the schwa stimuli. Percentages have been classified according to contextual consonant condition, i.e. LAB (labial), /l/ (alveolar lateral), DA (dentoalveolar) and PAL (palatal).

Before drawing a comparison between the vowel identification and production data, it is appropriate to report the statistical analysis results for the context-dependent differences in F1 and F2 frequency for the schwa productions which were selected as perceptual stimuli. ANOVAs run on those data achieved significance for F2 ($F(3, 16) = 11.47$, $p = 0.0003$) but not for F1, thus indicating that stressed schwa is far more sensitive to spectral changes induced by the contextual consonants on F2 than on F1. Moreover, according to the pairwise comparisons run on the F2 data, the frequency values for schwa in the context of palatal and dentoalveolar consonants turned out to be significantly higher than those occurring in the context of labials and /l/, while the palatal *vs* dentoalveolar and labial *vs* /l/ context differences were non-significant. This scenario is apparent in Figure 1 (bottom), where F2 for schwa occurs at 1500-1600 Hz in the DA and PAL environments (and may reach 1700 Hz in the PAL context) and lies between 1050 Hz and 1400 Hz in the LAB and /l/ contextual conditions. Taking an F2 frequency of 1500 Hz as reference for schwa, the former values occur above this frequency (which is in line with the production of dentoalveolar and palatal consonants involving tongue fronting and raising) and the latter below it (which accords with dark /l/ being articulated with some predorsum lowering and postdorsum retraction and labials exerting coarticulatory effects in lip closing but not in lingual configuration on schwa). Regarding F1, the vowel frequency ranges are very similar for all four consonant context conditions, i.e. 550-650 Hz in the case of the LAB and /l/ contexts and 500-600 Hz for the DA and PAL ones.

The ANOVAs performed on the formant frequencies for the entire dataset (see section 4.3.3) yielded significant effects for both F1 ($F(3, 132) = 19.07$, $p < 0.0001$) and F2 ($F(3, 132) = 264.81$, $p < 0.0001$), which were related to analogous but more fine-grained significant contextual differences than the ones reported above for the analysis performed on the formant frequency values for the perceptual stimuli: PAL > DA > LAB, /l/ for the F2 data; and /l/ > LAB, DA, PAL and LAB > DA in the case of F1. Sensitivity differences between the two statistical tests were due to differences in population size.

A comparison between the vowel identification results and the formant frequency values for the 20 stimuli which were included in the perception test reveals the following. (This comparison will be carried out taking also into account the formant frequencies for the peripheral vowels of Central Catalan reported in Recasens & Espinosa 2006).

Let us first look at the F2 frequency values for stressed schwa next to labials and /l/. The relatively low F2 for these stimuli, i.e. 1050-1400 Hz, explains why they were often heard as /a/ and, albeit much less so, as /ɔ/ in the context of /l/ (F2 for /a/ and /ɔ/ in Central Catalan amount to 1360 Hz and 1125 Hz, respectively). Unexpectedly, however, the schwa stimuli next to labial consonants were seldom heard as /a/ (or /ɔ/) perhaps because listeners took into account the fact that, differently from the other three consonantal environments, coarticulatory effects exerted by labials on vowels occur in the acoustics but not in tongue position. Moving to the other two contextual consonants, the fact that F2 for /ɛ/ in Central Catalan (1700 Hz) happens to be closer to F2 for schwa next to palatal consonants (1500-1700 Hz) than schwa next to dentoalveolars (1500-1600 Hz) could explain why the percentage of /ɛ/ responses was so much higher in the former context condition relative to the latter. Moreover, the schwa stimuli in these two consonantal contexts, dentoalveolar and palatal, were identified sometimes as /e/ in spite of the fact that their F2 was lower than F2 for /e/ in Central Catalan (1840 Hz). A final remark needs to be added about why stressed schwa was identified as /ə/ in the context of labials and /l/ rather than when occurring next to dentoalveolar and palatal consonants. The reason may be that a cross-contextual mean F2 of 1390 Hz for this Majorcan Catalan vowel (see Recasens & Espinosa 2006) happens to be closer to the vowel F2 in the former two consonantal environments (1050-1400 Hz) than in the latter two (1500-1700 Hz). As also pointed out earlier, the reason for this difference appears to be that consonants involving tongue body fronting and raising (dentoalveolars, palatals) induce larger spectral changes on schwa than those articulated with a lower and more retracted tongue body (dark /l/) or no lingual activity at all (labials).

As confirmed by the statistical analysis results, F1 appears to contribute less than F2 to the vowels identified in the perceptual test. For three consonant context conditions F1 for schwa was not clearly in agreement with the perceptual results: F1 in the context of labials and /l/ (550-650 Hz) happens to be closer to F1 for /ɔ/ (610 Hz) than to F1 for /a/ (730 Hz) in Central Catalan, while F1 in the context of dentoalveolars (500-550 Hz) lies between F1 for /e/ (450 Hz) and F1 for /ɛ/ (580 Hz). Things look much better for stressed schwa in the palatal context condition whose F1 (550-600 Hz) lies close to F1 for /ɛ/ in the Central Catalan dialect (580 Hz) and thus to the vowel which stressed schwa was most often confused with. Similar F1 frequency ranges for /ə/ in the context of labials and palatals cannot easily account for why the vowel was heard more often as schwa in the former context than in the latter (according to Recasens & Espinosa 2006, F1 for stressed schwa in Majorcan Catalan has a mean value of 560 Hz).

In sum, the perceptual data reported in this section show that there is a fairly good agreement between the context-dependent F2 frequencies for stressed schwa produced by Majorcan Catalan speakers and the F2 and articulatory characteristics of the vowels which were heard by the Central Catalan participants in this study when the schwa stimuli were presented to them for identification. Depending on the consonant environment, when the elicited vowels other than schwa are taken into consideration, stressed schwa was heard mostly as /ɛ/ (and less so as /e/) when adjacent to palatals and dentoalveolars, and as /a/ (and much less so as /ɔ/) when adjacent to labials and /l/.

4.4. Summary

Regarding the substitution of stressed schwa by other vowels, descriptive data and results from a perceptual identification test reveal a robust trend for schwa to be confused with the relatively long and spectrally similar vowels /ɛ/ and /a/. Schwa is likely to be replaced by /a/ in unstressed position perhaps because /ɛ/ is not an available option in this case and /e/ is spectrally too far away from schwa. Moreover, whether listeners tend to identify stressed schwa as /ɛ/ or /a/ may depend on the consonantal context in ways which are consistent with the corresponding consonant-to-vowel coarticulation effects in the acoustic signal: the mid central vowel may be heard as /ɛ/ and much less so as /e/ in the context of palatals and dentoalveolars, and as /a/ and much less so as /ɔ/ next to labials and the dark alveolar lateral.

Taken together, these findings may account for the replacement of /ə/ by /ɛ/ in stressed position in, among other dialectal domains, Balearic Catalan localities, though only if we assume that /ə/ had a relatively high F2 at the time that this sound change took place, whether because it was articulated quite anteriorly across consonantal contexts or because it occurred most frequently in the context of consonants produced with a fronted tongue body (palatals, several dentoalveolars) across the lexicon. Moreover, it may be suggested that for stressed schwa to be identified as /ɔ/ or another mid back vowel, its F2 must be lower than the F2 frequency of the acoustic stimuli used in our perceptual test and consequently that it should be produced with a narrower postdorsal constriction at the pharynx, which is where /ɔ/ is articulated.

5. Discussion

Acoustic and typological data reported in the literature reveal that, in spite of appearing in stressed position and for a representative number of languages, schwa is relatively short and contextually variable, which is in line with its being a central vowel lacking a clear-cut constriction location. Acoustic variability occurs in the F1 and F2 frequencies, i.e. the vowel oscillates between mid high and mid low and its F2 may correspond to a more posterior or a more anterior vowel realization. Acoustic data suggest that, compared with its unstressed cognate, stressed schwa is articulated with somewhat more postdorsal retraction and allows for less contextual variability.

These articulatory and acoustic characteristics are consistent with some distributional constraints on the appearance of stressed schwa: in a number of languages, this vowel is prone to occur in syllable and word positions favouring vowel shortening and thus in checked *vs* open syllables and in proparoxytones; in several languages, it only occurs if the other vowels in the word are either schwa or phonetically comparable to schwa in terms of duration. These features are also in accordance with various sound changes. Segmental duration appears to play a role in the emergence of stressed schwa in so far as its vowel source may be short high, mostly if front, mid high front and short low; spectral similarity is also involved since stressed back rounded vowels, and in particular mid ones, do not usually shift to schwa. It should be noted that this vowel centralization mechanism differs in important respects from other more widespread changes that may operate on mid vowels depending on whether they are longer in open syllables or shorter in checked syllables. As pointed out by Straka (1959), mid high /e/ and /o/ may lower to [ɛ] and [ɔ] in checked syllables given that when shortened, their tongue dorsum articulator falls short of the appropriate constriction degree and the jaw is placed lower than in open syllables; regarding mid low /ɛ/ and /ɔ/, on the other hand, articulatory undershoot causes these vowels, when shortened, to become less open and thus to raise to [e] and [o]. It has also been hypothesized that, while vowel tensing in open syllables enhances vowel contrasts by providing more distinct formant frequency values, vowel laxing in closed syllables may serve to enhance the differences in place and manner of articulation among consonants occurring in coda position (Storme 2019). As pointed out by a reviewer, in languages with distinctive vowel length the emergence of stressed schwa appears to involve the enhancement of length contrasts by quality differences, with the short vowel centralizing.

The present study also reports an asymmetry between those stressed vowels that give rise to schwa and those which may emerge from stressed schwa. While emerging mainly from short high, mid high front and short low vowels (see above), stressed schwa is commonly replaced by (mid) low vowels, which happen to be longer than their (mid) high cognates. Unstressed schwa is likely to be replaced by [a], the option [ɛ] being in principle discarded since this vowel is not prone to occur in unstressed syllables in the world's languages. A feasible explanation for the replacement of stressed schwa by [ɛ] and [a] is based on spectral affinity, i.e. the formant frequencies of stressed schwa are more similar to the formant frequencies of these vowels than they are to those of other vowels such as [e]. Moreover, according to the results from the perception identification test described here, whether the sound change outcome is one vowel or the other appears to depend on the articulatory characteristics of the contextual consonant(s): the replacement by [a] is most likely to occur next to consonants which contribute to lowering F2 in so far as they are produced with a lowered and retracted tongue body, while the replacement by [ɛ] takes place next to consonants produced with a relatively high and front tongue body configuration which causes F2 to rise. This finding suggests that whether stressed schwa shifts to [ɛ] or [a] in specific languages may be related to the frequency of occurrence of one subset of consonants or the other. Results from the perceptual identification test also suggest that for stressed schwa to be categorized as /ɔ/, its F2 needs to lower considerably, which is likely to result from an increase in postdorso-pharyngeal constriction degree.

Two main sound change mechanisms may have contributed to the generation of stressed schwa, probably in languages where this event is not likely to be associated with segmental shortening in obvious ways. The emergence of stressed schwa may have been induced by assimilation to instances of unstressed schwa occurring in the same word. This assimilatory mechanism is in line with schwa being much more prone to occur in unstressed than stressed syllables in the world's languages such that, with a few exceptions, if a language is endowed with stressed schwa in its vowel inventory it will also have schwa in unstressed position. Moreover, it is also the case that the two schwa types, stressed and unstressed, often co-occur in the same word. The contribution of the contextual consonants to the replacement of stressed /e/ by schwa appears to be assimilatory when involving tongue body retraction (next to the alveolar trill, dark /l/, retroflex dentoalveolars and also velars) and lip closing (next to labials) since in all these cases the corresponding consonant-to-vowel coarticulatory effects cause a decrease in F2 and possibly also in F3 to occur. The directionality of these assimilatory processes is in accordance with that of the corresponding coarticulatory effects, and therefore may be progressive and regressive when exerted by labials and the alveolar trill, and is always regressive when triggered by dark /l/ and retroflexes.

Spectral changes induced by velopharyngeal coupling account for why nasalized mid front and low vowels may shift to schwa in stressed position. Finally, /e/ centralization next to palatal consonants appears to be dissimilatory and could be associated with some vowel shortening induced by the characteristics of consonants articulated in this location.

While, as explained above, segmental shortening and coarticulation contribute to the presence of schwa in stressed position, the relative weight of the two factors appears to vary depending on the language taken into account. Thus, in Romance, the historical change /e/ > [ə] may have been associated with segmental shortening in languages of the Gallo-Romance family where vowel length and syllable structure contribute actively to differences in vowel duration, and presumably with consonant and unstressed vowel coarticulation in other languages such as Romanian and Occitan and Catalan dialects where vowel length is not contrastive and vowel duration is not primarily conditioned by syllable structure.

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