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Sonority-related markedness drives the misperception of unattested onset clusters in French listeners

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Abstract

Listeners often misperceive speech contexts that contain unattested, ill-formed phonological sequences and repair them to create well-formed or close-to-native sequences. However, what guides the misperception and repair processes still has to be studied in depth. In the present study, French adults and typically-developing children were presented aurally with monosyllabic pseudowords and their disyllabic /u/-inserted counterparts, with the well-formedness of the latters' onset clusters being manipulated (e.g., /ʁbal/ vs. /gmal/). Here, we showed that onset clusters are increasingly misperceived as universal sonority-related markedness increases, i.e., from the most well-formed through to the most ill-formed onset clusters (e.g., /gm/ → /bd → /ʁb/). *A posteriori* measurements confirmed that the misidentification is due to a phonological repair during which an *illusory epenthetic* /ə/-like vowel, i.e., a prototypical vowel inserted in French (e.g., /ʁəb/), is inserted in order to restore an attested phonological CV syllable structure. But these patterns are not primarily affected by acoustic-phonetic cues or sonority-unrelated cues. Moreover, both sensitivity to universal sonority-related markedness and epenthetic repair were found to be available at an early age in children. These results strengthen the hypothesis that acoustic-phonetic cues and language-specific properties, such as statistical properties for example, *are not solely responsible* for speech perception.

Keywords

Sonority; Markedness; Speech perception; Epenthesis; French.

Résumé

Traiter une structure phonologique qui n'existe pas dans une langue ou qui ne respecte les contraintes linguistiques a généralement pour conséquence une transformation, voire même une réparation de celle-ci. Pourtant, il demeure de nombreuses zones d'ombre sur ce qui influence ces deux processus. Notre étude proposait d'étudier ces phénomènes auprès d'adultes et d'enfants français en leur administrant une tâche de comptage syllabique en perception auditive. Nous avons utilisé des non-mots monosyllabiques et leurs contreparties dissyllabiques contenant une voyelle /u/ (e.g., /gmal/ et /gumal/). Nous avons également manipulé un continuum de légalité d'attaques syllabiques non attestées en français en nous appuyant sur le marquage de sonorité (de légal à illégal ; e.g., /gm/ → /bd/ → /ʌb/). Nos résultats indiquent clairement une sensibilité au marquage de sonorité : plus une attaque syllabique était illégale, plus les participants avaient tendance à la réparer phonologiquement avec une voyelle épenthétique illusoire, prototypique du français (e.g., /kəb/). Ces profils de réponse ont été observés aussi bien chez les enfants que chez les adultes, sans qu'ils ne soient expliqués par les propriétés acoustiques, phonétiques et statistiques des structures phonologiques, relançant le débat sur le rôle de la sonorité pour la segmentation et la réparation syllabique.

Mots-clés

Sonorité ; Marquage ; Perception de parole ; Épenthèse ; Français.

1. Introduction

What happens when speakers encounter phonological sequences that are unattested¹ and/or ill-formed in their native language? This question has been central to recent studies that have investigated the universal linguistic knowledge imposed on onset clusters in native speakers of English, Korean, Russian, and Spanish (e.g., Berent, Lennertz, Jun, Moreno, & Smolensky, 2008; Berent, Lennertz, & Rosselli, 2012a; Berent, Lennertz, Smolensky, Vaknin-Nusbaum, 2009; Berent, Steriade, Lennertz, & Vaknin, 2007). More specifically, these studies have attempted to examine whether –and how– the *Optimality Theory* framework (e.g., Prince & Smolensky, 1997; 2004) is able to make universal grammatical constraints available to all listeners in all languages and thus permits the (mis)perception of unattested, ill-formed onset clusters. The present research examines whether –and how– 1) the *phonological sonority-related markedness* is universal, and available to native speakers of French and permit the (mis)perception of unattested onset clusters; 2) native speakers of French use a phonological repair involving an *illusory epenthetic vowel* for unattested, ill-formed onset clusters.

For several decades, research has investigated how quickly and automatically speech perception converts acoustic signals into phonological representations (e.g., Massaro, 2001). It is now well-known that speakers' perceptual systems attune to (i.e., analyze, adjust, and learn) the encountered speech dynamically and at an early age even if the phonological sequences are unattested or ill-formed (e.g., Kuhl, 2004; Massaro, 2001; Saffran, Werker, & Werner, 2006). For instance, perceptual assimilation or compensation for coarticulation are well-known processes that turn unattested, ill-formed phonological sequences into attested, well-formed sequences in a target language (i.e., /dla/ → /gla/; e.g., Diehl, Lotto, & Holt, 2004; Hallé, Seguí, Frauenfelder, & Meunier, 1998; Iverson, Kuhl, Akahane-Yamada, Diesch, Tohkura et al., 2003; Moreton, 2002; Pitt, 1998; Redford, 2008; Viswanathan, Magnuson, & Fowler, 2010). Perceptual confusion and repair processes have been attributed to the way the perceptual system is adapted in accordance with native speakers' phonological knowledge which comprises language-specific sounds (i.e., phonemes) as well as linguistic constraints (i.e., phonotactics) that constrain the co-occurrence of phonemes and govern the well-formedness and distinctiveness of phonological sequences (i.e., phonotactic constraints – and transitional probabilities² –; e.g., Auer & Luce, 2005; Bailey & Hahn, 2001; 2005; Samuel, 2011). However, alternative processes have been reported in adults.

Extensive typological surveys have shown that certain phonological sequences are preferred to others across languages. It has been reported that simple CV syllables (C stands for consonant and V for vowel) are more frequent than complex ones across different languages (e.g., CCV, CVC; e.g., Blevins, 2004). It is worth noting that languages that tolerate complex syllables also systematically accommodate simple syllables embedded in the complex ones (e.g., languages with CCV or CVC syllables include CV syllables; e.g., Greenberg, 1978). No language that allows complex syllables (e.g., /pʁei/, *pray*) disallows simple ones (e.g., /peɪ/, *pay*; see Clements & Keyser, 1983). However, a language that allows simple syllables can disallow complex ones (e.g., Japanese). Languages that make use of universally underrepresented onset clusters (e.g., /ʁb/-type clusters) also contain universally overrepresented ones (e.g., /bʁ/-type clusters), whereas the opposite is not true (e.g., Greenberg, 1978; Hyman, 2008; Tobin, 2002). Researchers have also examined how these universal constraints are represented in speakers' phonological systems in a wide range of languages (i.e., English, Korean, Russian, and Spanish; e.g., Berent et al., 2007; 2008; 2012a). For instance, Berent et al. (2007; 2008) conducted cross-linguistic studies into the *status* of unattested or ill-formed onset clusters (e.g., /bd/ and /lb/). What Berent et al. (2007; 2008) showed is that not all the onset clusters are processed in the same way. Phonological sequences like /lb/, which are universally *dispreferred* in onset clusters, induce more misperceptions and repairs into /ləb/ than phonological sequences such as /bl/ which are universally preferred as onset

¹ In the following, we distinguish between “unattested”, which relates to phonotactically-illegal (e.g., /gm/ in onset clusters in French) or non-native phonological sequences (e.g., /dzi/), and “ill-formed”, which refers to phonological sequences that do not conform to universal linguistic principles (e.g., /sp/ in onset clusters in French). Consequently, an onset cluster may be unattested and ill-formed (e.g., /ʁb/) or unattested and well-formed (e.g., /gm/).

² Phonotactic restrictions and – transitional – probabilities refer to the language-specific rules that govern how, and how frequently, phonemes occur and co-occur in languages (e.g., /mz/ never occurs in French onset clusters, and is therefore phonotactically illegal, whereas /kl/ is of low phonotactic probability (e.g., /klaksɔ̃/, *horn*) and /pʁ/ is of high phonotactic probability (e.g., /pʁi/, *price*). Both of the latter are phonotactically legal).

clusters and only infrequently repaired into /bəl/. Berent et al. (2007; 2008) interpreted preferences such as these in terms of consonant *sonority* (e.g., Clements, 1990; 2006; Parker, 2002).

Even if the concept of sonority is an important one, the issue of what it is and how to define it remains controversial. More specifically, its nature and origins are a matter of debate. Is sonority a formally-grounded linguistic constraint (i.e., an innate linguistic primitive) or a functionally-grounded linguistic constraint derived from speakers' linguistic experience of the acoustic-phonetic properties of sounds (e.g., Hayes & Steriade, 2004)? How does sonority reflect a phonetically-grounded or acoustically-grounded phonological constraint? Clements (1990; 2006), for example, emphasizes the elusive phonetic correlates in sonority, while Parker (2008) considers that phonological sonority has concrete, quantifiable physical and perceptual properties. Indeed, it has been proposed that sonority is a phonological property of sounds, whose acoustic intensity is the most reliable correlate (e.g., Ladefoged, 2001; Parker, 2002). Sonority, therefore, is envisaged as a universal, formal, scalar, feature-like phonological element that categorizes all speech sounds into a hierarchical acoustic-phonetic scale (e.g., Clements, 1990; 2006; Parker, 2002). Sonority thus ranks consonants from high-sonority phonemes (i.e., from liquid to nasal – labeled as *sonorant* –) to low-sonority ones (i.e., from fricative to occlusive – labeled as *obstruent* –; Fig. 1). This argues in favor of universally optimal syllables that tend to conform to the *sonority sequencing principle* (SSP, henceforth; Clements, 1990; 2006). SSP describes a syllable's *sonority profile* (SP, henceforth) which follows both a *sonority distance* gradient and a *sonority dispersion* based on the computation of the sonorities of the individual consonants in a syllable. The sonority distance describes the tendency of sonorities to rise by at least x degrees from C_1 to C_2 in a C_1C_2 cluster (e.g., Selkirk, 1984). The sonority dispersion principle posits that in a C_1C_2V syllable, each element has to be maximally distant in terms of sonority (e.g., Clements, 1990)³. According to the SSP, in an optimal syllable SP, the onset tends to grow maximally in sonority towards the vowel and then fall minimally to the coda (although some languages, such as Russian, tolerate consonant clusters that violate the SSP. This is also possible in French which, however, mostly adheres to the SSP; e.g., /spɔʁt/, *sport*). This pattern describes an optimal SP where /ta/ ($s = +4$) is better than /la/ ($s = +1$), and where /bl/ ($s = +3$) is better than /lb/ ($s = -3$).

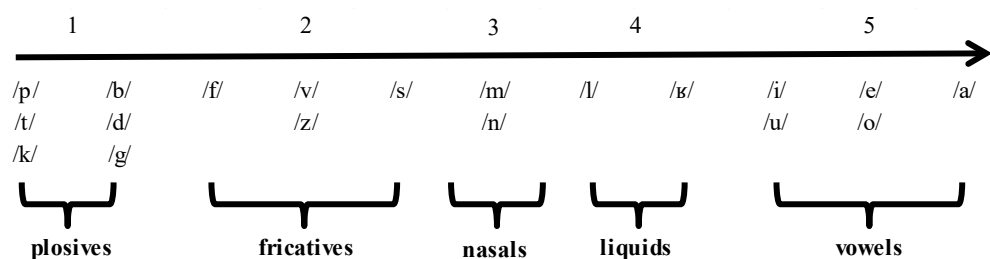


Figure 1. Sonority hierarchy adapted from Clements (1990) and Selkirk (1984).

Berent et al. (2007; 2008; 2009; 2012a) therefore claimed that the frequency with which phonological sequences are misperceived tends to be proportional to their phonological markedness (i.e., /lb/ > /bd/ > /bl/). Markedness inhibits unattested, ill-formed phonological sequences (i.e., labeled as *marked*; e.g., /ʁb/) and favor attested, well-formed ones (i.e., labeled as *unmarked*; e.g., /bʁ/). It is interesting to note that markedness has been traditionally assumed to result directly from sonority and, by extension, the SSP, so we consider it to be *universal phonological sonority-related markedness* that determines whether an onset cluster is well- or ill-formed: the least marked phonological onset cluster describes an SP that rises sharply towards the vowel (high-rise SP, e.g., /bʁ/, $s = +3$), while the most marked onset cluster describes an SP that falls sharply (high-fall SP, e.g., /ʁb/, $s = -3$). As s decreases, markedness gradually increases, and well-formedness gradually decreases: high-rise SP (e.g., /gʁ/, $s = +3$) > low-rise SP (e.g., /dv/, $s = +1$) > plateau SP (e.g., /tp/, $s = 0$) > low-fall SP (e.g., /ft/, $s = -1$) > high-fall SP

³ Here, we do not discuss these two principles separately. For the purposes of the present research, we have unified them as a general sonority distance principle (s , henceforth).

(e.g., /ʌb/, $s = -3$). In other words, /lb/ is problematic because it violates the SSP, while /bl/ is unproblematic since it respects the SSP⁴.

To summarize, Berent et al. (2007; 2008; 2009; 2012a) illustrate that native adult speakers of English, Korean, Spanish, and Russian possess linguistic knowledge that disallows ill-formed sequences in onset clusters but allow well-formed ones and rank them in terms of their sonority-related well-formedness (i.e., /lb/ > /bd/ > /bl/). This also seems to be true of English-speaking children (e.g., Berent, Harder, & Lennertz, 2011). Some of the studies conducted to date are consistent with the idea that sonority-related markedness results in the (mis)perception or mis(production) of clusters although this is conceivable that sonority-related markedness might not be isomorphic. For instance, one well-known response pattern in preliterate and literate children is the simplification of attested complex structures such as CVC or CCV syllables into simple CV syllables both in speech production and even in reading (i.e., 'tru' → 'tu'; 'bar' → 'ba'; e.g., Bastien-Toniazzo, Magnan, & Bouchafa, 1999). In a wide range of languages such as Dutch, English, French, or Spanish, this response pattern might depend on a preference to maximize sonority distance and eliminate sonorant consonants (e.g., Barlow, 2005; Demuth & Kehoe, 2006; Demuth & McCullough, 2009; Gnanadesikan, 2004; Hilaire-Debove & Kehoe, 2004; Kirk & Demuth, 2005; Levelt, Schiller, & Levelt, 1999; Maïonchi-Pino, de Cara, Écalle, Magnan, 2012a; 2012b; Marouby-Terriou & Denhière, 2002; McLeod, van Doorn, & Reed, 2001; Ohala, 1999; Sprenger-Charolles & Siegel, 1997; Wyllie-Smith, McLeod, & Ball, 2006). However, it is difficult to ascertain whether sonority-related universals are involved, in particular because these studies did not assess unattested or ill-formed onset clusters. There are also variations in children across languages and these are often anchored in sonority-unrelated elements (e.g., phonotactic transitional probabilities etc.).

Furthermore, what is important is what happens to speakers when they are faced with unattested or ill-formed phonological sequences. The above results indicate that (mis)perceptions are underpinned by a universal phonological repair and most speakers tend to 1) recode ill-formed clusters into well-formed clusters following their deviation from universal phonological sonority-related well-formedness; 2) restore a universally optimal and plausible CV alternation by adding an *illusory epenthetic vowel* extracted from their language-specific phoneme inventory (i.e., in English, Korean, or Russian, /lbif/ → /ləbif/; e.g., Berent et al., 2007; 2008; 2012a; but for an illusory prothetic vowel in Spanish, /lbif/ → /əlbif/, see also, e.g., Berent et al., 2012a; or for alternate SSP-based syllabification, resyllabification, and deletion strategies in English, see, e.g., Ettlinger, Finn, & Hudson-Kam, 2012). The insertion of an illusory epenthetic vowel to establish conformity with the syllable structures of a given language is a well-known phenomenon both in adults and children, which has been highlighted outside of the context of universal sonority-related markedness (i.e., in Japanese, /ebzo/ → /ebuzo/, in French, /ebzo/ → /ebəzo/, or in Brazilian Portuguese, /ebzo/ → /ebizo/; e.g., Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2011; Mazuka, Cao, Dupoux, & Christophe, 2011; Parlato-Oliveira, Christophe, Hirose, & Dupoux, 2010). Much of the research conducted has been interpreted in terms of coarticulation cues, phonotactic constraints and transitional probabilities, or language-specific acoustic-phonetic properties (e.g., Daland, Hayes, White, Garelleck, Davis et al., 2011; Davidson, 2011; Davidson & Shaw, 2012; Dupoux et al., 1999; 2011). Furthermore, there are conflicts between Berent, Lennertz, and Balaban's position (2012b), which considers that the misidentification of /lb/-like onset clusters and their repair into /ləb/ stem from an active process that phonologically decodes and recodes ill-formed onset clusters into well-formed ones, and authors who argue in favor of a passive failure to encode acoustic-phonetic properties and failure to accommodate coarticulation cues and bucco-phonatory constraints (e.g., Davidson, 2006; Davidson, 2011; Davidson & Shaw, 2012).

In sum, there are still unresolved issues and controversial accounts of the (mis)perception of universal phonological sonority-related markedness and the ways in which repair acts. In this paper, we present the results of ongoing research that does not focus on English but does include a language that has CC clusters. To anticipate whether sonority-related markedness is as universal as some authors have claimed, we consider another language that has not benefited from extensive research: French. On the

⁴ Here, we do not discuss the violation of the SSP in some languages (e.g., Russian).

one hand, French is of interest since it represents more than 75 million native speakers, and 190 million secondary speakers (e.g., Weber, 1997). On the other, French is a syllable-timed language (e.g., Cutler, 1997). Its phonological system mostly contains simple CV syllable structures as well as some complex syllable structures (e.g., CCV, CVC...) with C_1C_2 onset clusters that do not generally violate sonority-related markedness (e.g., Dell, 1995). Indeed, French is a language that tolerates onset clusters such as /bʁ/, but forbids onset clusters such as /ʁb/. Our research therefore addresses three related questions. First, if native speakers of French are equipped with universal linguistic knowledge such as sonority-related markedness, do the (mis)perception patterns resemble those reported by Berent et al. (2007; 2008; 2012a; 2012b)? To answer this question, we examined what happens when native speakers of French encounter unattested or ill-formed onset clusters such as /ʁb/ or /mɔ/. Second, if native speakers of French are able to repair phonological sequences in proportion to their sonority-related markedness, do they (mis)perceive an illusory epenthetic vowel that is language-specific? To determine whether native speakers of French (mis)perceive an illusory epenthetic vowel, we manipulated monosyllabic $C_1C_2VC_3$ pseudowords and their disyllabic $C_1uC_2VC_3$ counterparts (e.g., /ʁbal/ vs. /ʁubal/) along a fine-grained, progressive hierarchical continuum from the least marked and most well-formed onset clusters (e.g., /gʁ/, $s = +3$), to the most marked and most ill-formed onset clusters (e.g., /dv/, $s = +1$; /tp/, $s = 0$; /ft/, $s = -1$; /ʁb/, $s = -3$, respectively). If phonological repair depends on the sonority-related markedness, the proportion of illusory epenthetic vowels should increase from the least marked to the most marked onset clusters. We therefore predicted that the monosyllabic pseudowords would be misperceived as disyllabic. If an illusory epenthetic vowel improves the well-formedness of syllables in terms of the linguistic specificities observed in French, we would expect to find an illusory epenthetic /ə/-like vowel such as /ø/ or /œ/, which are referred to as the minimal and prototypical phonetic realizations or the *default vowels* for epenthesis in French (e.g., Côte & Morrison, 2004; Spinelli & Gros-Balthazard, 2007), regardless of acoustic-phonetic cues or language-specific properties (e.g., statistical properties). We also wanted to assess the *perceptibility* of the illusory epenthetic vowel in order to contribute to the discussion surrounding the controversial question of whether this vowel results from an active phonological process or whether the perceptual system fails to properly perceive and encode the acoustic-phonetic properties (see also Berent et al., 2012b, for a similar issue). Third, if universal phonological sonority-related markedness is available to native speakers of French who are able to perform a phonological repair based on an illusory epenthetic vowel, a further challenge lies in determining whether there are differences between children and adults (i.e., linguistic experience). Data relating to this question remains scarce. Previous research has shown that 4-to-5-year-old Spanish children and even 11-year-old dyslexic French children misperceive markedness in proportion to the ill-formedness of the onset clusters (i.e., /bɪf/ > /bdɪf/ > /blɪf/; e.g., Berent et al., 2011; Maionchi-Pino et al., 2013). This observation corroborates Parlato et al.'s findings (2010) suggesting that the phonological system is plastic only during childhood (until the age of 4) and permits the reorganization of the perceptual system in response to socio-cultural pressures. However, the question regarding the illusory epenthetic vowel remains unanswered. Previous research has found that speakers acquire the epenthetic vowel – or are able to (mis)perceive it – early in childhood, presumably through a statistical learning mechanism that infers it from partial but robust sequences of the phonological grammar before the corresponding lexical information becomes available (e.g., Mazuka et al., 2010). The difference between the studies cited above, however, lies in what is assumed to shape the acquisition of the epenthetic vowel: Berent et al. (2011) and Maionchi-Pino et al. (2013) did not show that the tendency of English or French children to (mis)perceive an illusory epenthetic vowel is caused primarily by statistical properties or obvious acoustic-phonetic properties, whereas Mazuka et al. (2010) and Parlato et al. (2010) did. In this study, our aim is to reveal whether markedness sensitivity fluctuates over time and whether a phonological repair based on the introduction of an epenthetic vowel depends on statistical properties in children who have benefited from a substantial but not, as yet, extensive exposure to their linguistic environment. We therefore asked 8-to-12-year-old children as well as young and elderly adults to perform a silent syllable counting task that allows to assess explicit phonological knowledge without cueing on sonority. We also chose this task since it facilitates a straightforward comparison with the results of Berent et al. (2007; 2008) who used a similar paradigm.

2. Method

2.1. Participants

Seventy-two monolingual native French speakers with no extensive experience of a foreign language participated⁵. They were divided into four groups: eighteen elderly adults ($M = 67.5 \pm 3.25$ years), eighteen young adults (university students; $M = 24.5 \pm 1.75$ years), eighteen 8-year-old children ($M = 8.0 \pm 1.25$ years), and eighteen 12-year-old children ($M = 11.25 \pm 1.5$ years).

2.2. Material

The experimental stimuli consisted of 20 monosyllabic $C_1C_2VC_3$ pseudowords (e.g., /pkal/) and their disyllabic $C_1uC_2VC_3$ counterparts (e.g., /pukal/; see Appendix). All the pseudowords shared the same VC_3 rhyme (i.e., /al/) but had a different C_1C_2 onset clusters. Homorganic consonants⁶ (i.e., consonants that share the same place of articulation and are considered to be more complex than heterorganic consonants at both the phonetic and articulatory levels, and also more likely to lead to compensation for coarticulation as well as to the delaying or mistiming of the articulatory output due to a greater gestural overlap; e.g., Jakielski, 2002) and voicing differences were avoided within the C_1C_2 clusters (regressive/progressive voicing assimilation). C_1 and C_2 could have a different manner of articulation (i.e., obstruent, fricative, nasal, or liquid). We referred to Dell's (1995) list to select our C_1C_2 onset clusters, which ensured that our monosyllabic $C_1C_2VC_3$ pseudowords had an onset cluster that is unattested in word-initial position in French⁷. These unattested C_1C_2 onset clusters were divided into 5 SPs: high-fall (e.g., /ɸbal/), low-fall (e.g., /fkal/), plateau (e.g., /pkal/), low-rise (e.g., /kfal/), and high-rise (e.g., /zɸal/). Onset cluster markedness progressed from high-fall SPs (the most marked and most ill-formed) to high-rise SPs (the least marked and most well-formed). Each SP condition contained four different C_1C_2 clusters. Each C_1C_2 onset cluster was repeated five times within each SP. Consequently, 200 stimuli were administered as follows: $4 C_1C_2 \times 5 SPs \times 5 repetitions \times 2 pseudowords$ (mono- and disyllabic) = 200. The disyllabic $C_1uC_2VC_3$ counterparts were spoken by a female French native speaker (M duration = 628 ± 33 ms). All the sounds were digitally recorded, sampled at a rate of 44 kHz, converted at 16-bit resolution, and band-pass filtered (0 Hz to 5,000 Hz). We also wanted to avoid clear acoustic-phonetic cues or coarticulation traces resulting from a schwa-like vowel in intervocalic position (i.e., between C_1 and C_2), which might have led to the (mis)perception of a schwa – or schwa-like vowels such as /ə/ or /œ/ – as the default vowel for epenthesis when repairing marked, ill-formed clusters. We performed a trade-off by avoiding schwa-like vowels that are front-rounded and therefore typologically marked (e.g., de Lacy, 2006) and selecting the vowel /u/, which is a back-rounded, typologically unmarked vowel. The $C_1uC_2VC_3$ pseudowords contained a full intervocalic /u/ vowel⁸. We also made sure that the C_1u in our disyllabic pseudowords carried stress. Monosyllabic $C_1C_2VC_3$ pseudowords were obtained by splicing out step-by-step the pitch periods of the /u/ using Praat software (Boersma & Weenink, 2011; method similar to that used by Dupoux et al., 1999). Their waveforms were visually and auditorily inspected to minimize /u/ coarticulation-based traces in C_1 and C_2 . The mean duration was 204.1 ± 12.8 ms for the C_1C_2 clusters, while the mean /u/ vowel duration was 98.6 ± 11.9 ms.

2.3. Procedure

The script was designed, compiled and run with E-Prime 2 Professional (Schneider, Eschman, & Zuccolotto, 2002) on Sony X-series laptop computers running under Windows 7. The participants wore Sennheiser HD 25-1 II headphones (16-22 kHz range, 70 Ω impedance) and sat in a soundproof room. The sounds were administered binaurally at 65 dB SPL. Each trial progressed as follows: a 500-ms

⁵ The participants were right-handed (M right-handedness score = $+0.82 \pm 0.06$ measured with the Edinburgh Handedness Inventory (Oldfield, 1971)) and reported no hearing disorders. This research received the approval of the local Ethics Committee.

⁶ We used the homorganic consonant classification as follows: labial (i.e., /p/, /b/, /f/, /v/, and /m/), coronal (i.e., /n/, /t/, /d/, /l/, /s/, /z/, /ʃ/, and /ʒ/), and dorsal (i.e., /k/, /g/, and /ɣ/).

⁷ We do, however, acknowledge that some C_1C_2 clusters could also appear within syllable boundaries or in word-final position (e.g., /ɸb/ in /aɸbitɸ/, *referee*) and accept that this could have affected the participants' perception. We therefore included the phonotactic transitional probabilities in our linear stepwise hierarchical regression analysis.

⁸ We used /u/-like vowel to ensure that possible coarticulation-based traces did not influence the epenthetic vowel that was expected to be a schwa-like vowel.

vertically-centered fixation cross (i.e., '+') was displayed and then replaced by a blank screen displayed for 200 ms before the sound was played. A white noise (± 250 ms) followed each response from the participant. The inter-trial interval was 750 ms. The participants were asked to indicate as quickly and accurately as possible whether the pseudowords had one or two syllables (numpad 1 = one syllable, numpad 2 = two syllables). The participants were first familiarized with a practice list of 16 trials with corrective feedback. No feedback was given for the experimental trials. The familiarization phase was proposed primarily to illustrate the task for the children and implicitly to make them aware of what mono- and disyllabic pseudowords are (our positive or negative feedback did not indicate what it was that made the words mono- or disyllabic). The trials were randomized. Response times and response accuracy were automatically recorded.

3. Results

We used Statistica 8.0[®] software (StatSoft[®], 2011) to run a $5 \times 2 \times 4$ mixed-design repeated-measures analysis of variance (ANOVA) by subject (F_1) and by item (F_2) for response times (RTs) and response accuracy ($\pm 85.8\%$ of the data) with Sonority profile (high-fall; low-fall; plateau; low-rise; high-rise) and Syllable (monosyllabic; disyllabic) as within-subject factors; and Group (elderly adults; young adults; 8-year-old children; 12-year-old children) as between-subject factor. Correct RTs were trimmed (i.e., for each subject. RTs that deviated by more than 2 standard deviations from the mean were replaced by the mean RT for the subject, 2.5% of the data).

3.1. Response times and accuracy analyses

The ANOVA showed a significant main effect of Group on response accuracy, $F_1(3, 68) = 9.87, p < .0001, \eta^2_p = .40, F_2(3, 120) = 10.19, p < .0001, \eta^2_p = .20$, and response times, $F_1(3, 68) = 6.20, p < .0001, \eta^2_p = .25, F_2(3, 120) = 9.93, p < .0009, \eta^2_p = .17$. There was also a significant main effect of Syllable structure on response accuracy, $F_1(1, 68) = 11.70, p < .002, \eta^2_p = 0.21, F_2(1, 120) = 13.90, p < .0003, \eta^2_p = .10$, and response times, $F_1(3, 68) = 6.96, p < .0001, \eta^2_p = .18, F_2(1, 120) = 8.99, p < .007, \eta^2_p = .12$. Tukey HSD post-hoc tests (Bonferroni adjusted α level for significance, $p < .008$) confirmed that only the 8-year-old children were significantly slower and less accurate (1,717 ms; 84.5%) than the 12-year-old children (1,498 ms; 87.3%), young adults (1,450 ms; 87.8%), and elderly adults (1,624 ms; 87.7%; $p_s < .0001$). Overall, syllable counting was slower and less accurate for monosyllabic (1,610 ms; 87.7%) than for disyllabic pseudowords (1,535 ms; 86.0%). The descriptive data and correlations are reported in Table 1. The Syllable structure \times Sonority profile interaction was significant for response accuracy (Fig. 2), $F_1(4, 268) = 153.12, p < .0001, \eta^2_p = .78, F_2(4, 120) = 52.48, p < .0001, \eta^2_p = .57$, and response times, $F_1(3, 268) = 11.82, p < .0001, \eta^2_p = .21, F_2(4, 120) = 22.13, p < .0001, \eta^2_p = .33$. Tukey LSD post-hoc tests (Bonferroni adjusted α level for significance, $p < .0011$) showed that response accuracy progressively decreased and response times progressively increased from high-rise SPs (e.g., /zʁal/) to high-fall SPs (e.g., /ʁbal/) for the monosyllabic pseudowords, whereas response accuracy increased both significantly and progressively from high-fall SPs to high-rise SPs for their disyllabic counterparts. For both mono- and disyllabic pseudowords, all the differences between high-fall SPs and low-fall SPs, low-fall SPs and plateau SPs, plateau SPs and low-rise SPs, and low-rise SPs and high-rise SPs reached the statistical significance threshold for response accuracy only, $p_s < .05$.

The three-way Sonority profile \times Syllable \times Group interaction was not significant for response accuracy or response times, $F_s < 2, p_s > .1^9$.

⁹ Additional analyses (not described here) revealed significant statistical differences, with high-rise SPs, plateau SPs, and high-fall SPs involved in the Sonority profile \times Syllable interaction in all groups.

Table 1. Mean response times (in ms), mean response accuracy (in %), standard deviations (in brackets) for Group, Syllable structure, and Sonority profile.

	Elderly adults		Young adults		12-year-old children		8-year-old children	
	monosyllabic	disyllabic	monosyllabic	disyllabic	monosyllabic	disyllabic	monosyllabic	disyllabic
High fall SP	77.9 (2.9) 1,790 (254)	96.7 (2.9) 1,498 (290)	76.7 (2.7) 1,617 (168)	97.1 (2.0) 1,283 (198)	79.6 (3.3) 1,631 (177)	96.3 (1.9) 1,352 (158)	75.0 (3.7) 1,857 (149)	92.1 (2.9) 1,616 (214)
Low fall SP	82.9 (2.9) 1,736 (208)	93.3 (2.7) 1,475 (194)	84.2 (2.8) 1,579 (156)	95.8 (2.1) 1,330 (180)	78.3 (3.5) 1,653 (154)	92.1 (2.5) 1,381 (153)	77.1 (2.9) 1,823 (159)	94.2 (2.8) 1,560 (204)
Plateau SP	85.0 (3.5) 1,648 (311)	86.3 (3.0) 1,589 (113)	86.3 (3.7) 1,458 (204)	87.9 (2.7) 1,409 (210)	87.1 (3.3) 1,508 (37)	85.8 (3.0) 1,510 (207)	83.8 (3.2) 1,719 (148)	84.2 (3.8) 1,731 (187)
Low rise SP	95.4 (2.0) 1,642 (251)	86.7 (3.5) 1,639 (195)	90.4 (1.7) 1,434 (181)	82.9 (2.9) 1,525 (145)	94.2 (2.6) 1,433 (173)	86.7 (2.2) 1,491 (187)	86.7 (3.9) 1,739 (189)	82.9 (4.6) 1,699 (163)
High rise SP	94.6 (2.8) 1,546 (153)	78.3 (2.7) 1,680 (184)	96.7 (2.0) 1,363 (215)	80.0 (4.0) 1,502 (168)	95.4 (2.5) 1,411 (166)	77.5 (2.7) 1,613 (192)	92.5 (2.5) 1,619 (181)	77.1 (2.7) 1,810 (163)
<i>Mean</i>	1,672 ms (87.2%)	1,576 ms (88.3%)	1,490 ms (86.9%)	1,410 ms (88.7%)	1,527 ms (86.9%)	1,469 ms (87.7%)	1,751 ms (83.0%)	1,683 ms (86.1%)
Correlation (<i>r</i>) response times / response accuracy	-0.75	-0.72	-0.87	-0.70	-0.79	-0.66	-0.67	-0.68

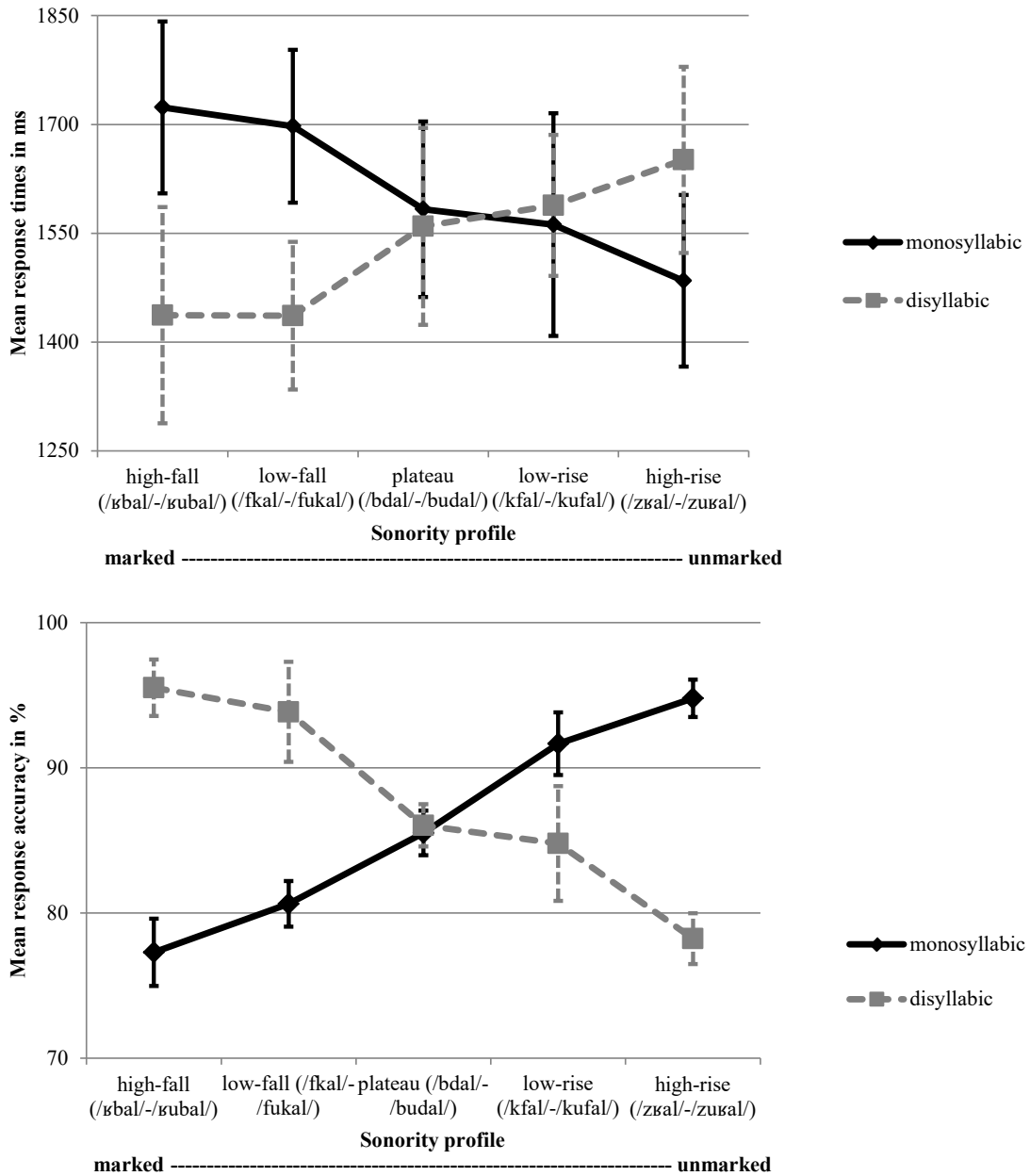


Figure 2. Mean response times (in ms; upper panel), mean response accuracy (in %; lower panel) and standard deviation bars for the Sonority profile \times Syllable interaction collapsed across groups.

3.2. Discrimination sensitivity and decision criterion

We also used the d' to test the discrimination sensitivity thresholds and the β to assess the decision criterion (i.e., *signal detection theory*; $d' = 0 \pm 5\%$ means random responses in the range from 47.5% to 52.5%; e.g., Macmillan & Creelman, 2005). Pairwise Student t -tests of the d' computed for each group showed that the discrimination sensitivity threshold in the 8-year-old children ($M = 2.06 \pm 0.17$) was significantly lower than in the 12-year-old children ($M = 2.29 \pm 0.13$, $t(34) = 3.74$, $p < .002$), young adults ($M = 2.35 \pm 0.17$, $t(34) = 4.15$, $p < .0005$), and elderly adults ($M = 2.34 \pm 0.17$, $t(34) = 4.03$, $p < .0006$). Values for d' did not vary significantly between the other groups ($p_s \geq .1$). Values for d' ($M = 2.26 \pm 0.93$) ranged from low-moderate sensitivity with difficult detection ($\min d' = 1.76$) to moderate-high sensitivity with easier detection ($\max d' = 2.63$). None of the participants had a $d' = 0 \pm 5\%$. Pairwise Student t -tests of the β computed for each group did not reveal significant differences concerning the decision criterion ($p_s \geq .1$) between the 8-year-old children ($M = 0.88 \pm 0.18$), 12-year-old children ($M = 0.97 \pm 0.16$), young adults ($M = 0.92 \pm 0.17$), and elderly adults ($M = 0.95 \pm 0.20$).

Values for β ($M = 0.93 \pm 0.17$) ranged from a trend towards a moderate liberalism ($\min \beta = 0.59$) to a trend towards a moderate conservatism ($\max \beta = 1.33$). Overall, there was no bias towards mono- or disyllabic responses.

3.3. Additional analyses

To assess low-level similarities in spectral or acoustic-phonetic contrasts between sonorant or voiced consonants and vowels, which are known to induce more /ə/-like transitional cues (e.g., Dupoux et al., 2011; Wright, 2004), we ran an *a posteriori* pairwise Student *t*-test. A /ə/-like vowel insertion in C₁C₂ clusters is most likely to occur in the presence of sonorant or voiced consonants than in the presence of obstruent or voiceless ones, and this induces a gestural mistiming (not discussed here; e.g., Hall, 2004).

On the one hand, our analyses involving monosyllabic pseudowords did not reveal significant differences between voiced-voiced C₁C₂ clusters ($n = 14$; e.g., /dv/) and voiceless-voiceless C₁C₂ clusters ($n = 6$; e.g., /pk/) in terms of either response accuracy ($p_s > .1$; 85.1% vs. 86.5%, respectively) or response times ($p_s > .1$; 1,614 ms vs. 1,602 ms, respectively) irrespective of the Sonority profile. Similarly, any confusability that led to the insertion of an epenthetic vowel could be due to the ambiguous distinctiveness of C₁C₂, so we further compared C₁C₂ clusters that included a sonorant consonant ($n = 9$; /l/, /ʁ/, or /m/) in either the C₁ or C₂ position as found in high-fall SPs (/lv/ or /ʁz/), low-fall SPs (/mʒ/), and high-rise SPs (/ʒʁ/ or /gm/) with C₁C₂ clusters that had two obstruent consonants ($n = 11$; /tf/ or /bd/). Pairwise Student *t*-tests did not reveal any significant differences between the two C₁C₂ cluster types, either in terms of response accuracy ($p_s > .1$; 84.5% vs. 86.3%, respectively) or response times ($p_s > .1$; 1,613 ms vs. 1,608 ms, respectively). On the other, we analyzed clusters containing non-continuant consonants ($n = 5$; /tp/, /bd/, or /dm/) compared to those containing continuant consonants ($n = 15$; /vz/, /ʁz/, or /mʒ/), or to those containing one of each in either C₁ or C₂ position ($n = 10$; /lg/, /ʁz/, or /tf/). A position-dependent analysis using pairwise Student *t*-tests showed that C₁C₂ clusters with one continuant and one non-continuant consonant did not differ from C₁C₂ cluster with two continuant consonants, either in terms of response accuracy ($p_s > .1$; 84.6% vs. 84.9%, respectively) or response times ($p_s > .1$; 1,649 ms vs. 1,631 ms, respectively) and differed only marginally from C₁C₂ clusters with two non-continuant consonants, both at the level of response accuracy ($p_s > .09$; 87.2%) and response times ($p_s > .08$; 1,547 ms). Finally, we compared the C₁C₂ clusters in terms of their place of articulation by searching for significant differences based on the direction of the clusters (i.e., forward from anterior to posterior regions; $n = 11$; /ʒg/, or backward from posterior to anterior regions; $n = 9$; /kf/). We observed no significant influence of the direction of C₁C₂ clusters either on response times (1,608 ms vs. 1,612 ms respectively, $p_s > .1$) or on response accuracy (86.0% vs. 84.9% respectively, $p_s > .1$).

We submitted French listeners' response accuracy to C₁C₂ clusters to linear hierarchically-forced stepwise regression analyses in order to test the language-specific cues (see Berent et al., 2007; 2008). We entered the C₁C₂ cluster length (in ms) in step 1, the statistical properties of biphones and triphones in steps 2 and 3 respectively (we used C₁VC₂ triphones with a vowel /ə/, which is the most frequently reported epenthetic vowel in French; e.g., /gm/-/gə̃m/; Gendrot, 2011), and the phonotactic transition probabilities in step 4 (Crouzet, 2000). Sonority-related markedness, as determined by the sonority distance, was entered last (step 5) and accounted for significant variance, although the triphone frequency with a schwa-like vowel also significantly contributed to the variance (step 3; see Table 2).

Table 2. Linear stepwise regression analyses in the response accuracy to monosyllabic pseudowords with hierarchically-forced entries of predictors.

	Step	Predictor	R ²	R ² change	F change	p-level	β
	1	cluster length (ms)	.01	.011	1.02	<i>ns</i>	-.10
	2	biphone frequency	.02	.004	< 1	<i>ns</i>	-.07
unattested onset clusters	3	triphone frequency (/ə/-inserted)	.11	.095	10.26	.002	.39
	4	phonotactic transitional probabilities	.11	.003	< 1	<i>ns</i>	.06
	5	markedness (sonority distance)	.26	.144	18.28	.0001	-.42

Even though we implicitly tested the perception of C₁C₂ clusters, the nature of the misperception was unclear. What did the participants (mis)perceive and what contributed to report an incorrect number of

syllables? To ensure that the response patterns indicating the presence of perceptual confusion were not due to coarticulation-based artifacts resulting from traces of the /u/ spliced from the C₁uC₂ clusters, as well as to determine whether misperception was due to active phonological processes that phonologically decode and recode the C₁C₂ clusters or were caused by a passive failure to encode and access the acoustic-phonetic properties, we post-tested our participants on the C₁C₂ onset clusters¹⁰. Neither the influence of the SPs nor the Group differences were analyzed. The participants, who had previously been implicitly required to count the syllables, were now asked to explicitly report whether they heard a vowel within our monosyllabic pseudowords, and if so, which one ($n = 100$; i.e., 4 C₁C₂ × 5 SPs × 5 repetitions). Response times were not recorded. Pairwise Student *t*-tests run on Group and Epenthetic vowel yielded significant results which are reported in detail in Table 3. The values reported in Table 3 therefore confirm the robustness of the epenthetic /ə/-like vowel across groups. In sum, the response patterns overlapped, and the participants misreported the presence of a vowel in 962 C₁C₂ onset clusters out of the total of 7,200 trials (12.8%), and most of these (815 errors) consisted of an epenthetic /ə/ ($M = 84.7 \pm 13.6$), rather than an epenthetic /u/ ($M = 8.5 \pm 10.4$), or other vowels ($M = 6.8 \pm 8.5$).

Table 3. Mean percentage of vowels reported (in %), standard deviations (in brackets), and pairwise Student *t*-tests as a function of the Group.

	Elderly adults	Young adults	12-year-old children	8-year-old children
/u/	9.6 (11.6)	7.6 (11.0)	8.8 (9.4)	8.0 (10.6)
/ə/	83.3 (11.7)***	88.5 (11.6)***	81.6 (17.2)***	85.4 (14.1)***
others	7.0 (7.2)	3.8 (7.0)	9.6 (11.3)	6.6 (7.9)
Mean % of misperception (100 stimuli per listener)	13.8 (4.3) ^a	10.5 (2.7) ^{a,b}	11.9 (4.0)	15.0 (4.7) ^b

Note: *** indicates $p < .0001$ for the Student *t*-test comparisons /ə/ vs. /u/ + others for each group; superscript letters stand for significant differences between groups (statistical threshold, $p_s < .05$).

4. Discussion

This paper presents the results of ongoing research undertaken in order to describe French native speakers' (mis)perception of unattested C₁C₂ onset clusters as determined by the universal phonological sonority-related markedness (e.g., Berent et al., 2007; 2008). In addition, a further aim of this research is to determine whether French native speakers attempt the phonological repair of unattested, ill-formed onset clusters using an *illusory epenthetic vowel*.

Our results are consistent with the idea of universal phonological sonority-related markedness and show that the French listeners in our study misperceived unattested, ill-formed C₁C₂ onset clusters as disyllabic. More importantly, our results show that universal sonority-related markedness, and hence well-formedness, guide how unattested C₁C₂ clusters are (mis)perceived. As markedness progressively increased from high-rise SPs (e.g., /gmal/), i.e. the unmarked and most well-formed clusters, to marked high-fall SPs (e.g., /ɛbal/), i.e. the marked and most ill-formed clusters, the French listeners in our study became increasingly likely to misperceive them as disyllabic. In other words, while French listeners mostly misperceive unattested C₁C₂ onset clusters that contain a sonority-related ill-formedness (e.g., /vz/¹¹ or /ɛb/), they do not misperceive as many unattested C₁C₂ onset clusters in which sonority-related well-formedness is respected (e.g., /gm/; 94.8% overall correct responses for high-rise SPs). It is interesting to note that these results confirm that the misperception is gradual and derives from an implicit knowledge of the hierarchical sonority-related markedness, which is not restricted to attested, native C₁C₂ onset clusters.

There was no speed-accuracy trade-off: the fastest responses were the most accurate whereas the slowest responses were the least accurate (Table 1). These response patterns confirmed previous results

¹⁰ The task was similar, except that for each error, a visual feedback was displayed and the participants were asked to press on the vowel they thought they heard (i.e., /a/, /i/, /u/, /o/, /e/, /ɛ/, /y/, /ə/, or no vowel). The participants were post-tested a few days later (± 12 days). Although we do not describe our analysis comparing the experimental and the post-test sessions, we observed that the response patterns and response trajectories overlapped in all groups.

¹¹ According to Clements' view (1990), plateau SPs are marked.

(e.g., Berent et al., 2008). Furthermore, the misperceptions cannot be attributed to the task requirements: the discrimination sensitivity threshold reflects low to moderately difficult detection ($M = 2.26$) with a nearly unbiased (i.e., $\beta = 1$) criterion decision ($M = 0.93$).

However, while the listeners' response patterns were consistent with the sonority-related markedness, there was no straightforward cue that indicated how the marked, most ill-formed C_1C_2 onset clusters were misperceived. In other words, we obtained no information about how the French listeners in our study misperceived these clusters as disyllabic. *A posteriori* measures, however, confirmed our expectations: sonority-related markedness induces a phonological repair involving the use of an illusory epenthetic vowel. Interestingly, this observation extends the findings of previous studies on this topic in other languages (e.g., in Japanese; Dupoux et al., 1999; in English; Berent et al., 2008). It also shows that the illusory epenthetic vowel may constitute a universal phonological repair mechanism, even though the nature of the vowel itself may be language-specific: in French, this phonological repair is performed using a prototypical /ə/-like vowel whose reported perception is obviously not influenced by the low-level similarities of spectral or acoustic-phonetic contrasts between sonorant consonants and vowels, continuant consonants and obstruent non-continuant consonants, or C_1C_2 clusters that contain voiced-voiced or voiceless-voiceless consonants (see Table 3; e.g., /aʁbal/ vs. /aʁəbal/; e.g., Peperkamp, 2007).

Furthermore, we discarded *a priori* both homorganic consonants and voicing assimilation contexts, which are speech contexts that are known to induce perceptual confusions. Additionally, *a posteriori* measures made it possible to discount the main influence of sonority-unrelated constraints. This clearly shows that our results cannot be basically accounted for in terms of underlying statistical properties. As can be seen in Table 2, markedness (in terms of sonority distance) mostly accounted for the variance ($p < .0001$). It is worth noting that this finding is consistent with previous evidence which has indicated that the processes involved in the misperception and repair of marked, ill-formed C_1C_2 onset clusters may not be solely attributable to language-specific properties (e.g., Berent et al., 2007; 2008; but see Dupoux et al., 2011). Also, the significance of the triphone frequency ($p < .002$) suggested that the nature of the epenthesis and the related phonological repair (i.e., a /ə/-like vowel in 84.7% of the misperception) stemmed from some statistical cues.

The crucial point is that our results provide a clear-cut argument in favor of the idea that French-speaking children and adults alike seem to be sensitive to sonority-related markedness. Perceptual confusion is not dependent solely on exposure to oral language. In general, from childhood to late adulthood response patterns exhibit a similar sensitivity to universal sonority-related markedness. More specifically, there was no difference between young and elderly adults who did not exhibit substantial changes in the sonority-related markedness (mis)perception whereas exposure to oral language – and also to written language – gradually increases. This suggests that the phonological knowledge about sonority-related markedness is not only early acquired but seems also to be stable over time beyond the implicit learning of statistical – and phonotactic – probabilities. The phonological repair, as testified to by the report of an epenthetic /ə/-like vowel, does not significantly change with age, despite exposure (or lack of it) to foreign languages, extensive exposure to the linguistic properties of one's native language, etc. The fact that even 8-year-old children exhibit sensitivity to sonority-related markedness – and, by extension, the SSP – strengthens the fact that this universal knowledge is acquired early and is properly ranked, adjusted, and possibly re-ranked to reflect the specificities of the French language. This is coherent with previous studies proposing that the SSP does function to guide the early children's phonological acquisition either its order, or reduction (e.g., Demuth & Kehoe, 2009; Gierut, 1999; Lleó & Prinz, 1996; Maïonchi-Pino, de Cara, Écalle, Magnan, 2012c; Sprenger-Charolles & Siegel, 1997). The children's response patterns thus confirmed and those of Maïonchi-Pino et al. (2013) obtained with French dyslexic children and their reading-level and chronological age-matched controls (ranges from 9;10 to 12;0 years old). Furthermore, our results extended previous results obtained in silent reading and visual identification tasks in French dyslexic and typically developing children (e.g., Fabre & Bedoin, 2003; Maïonchi-Pino et al., 2012a; 2012b; 2012c). Indeed, their studies showed that French children were able to use syllable-based segmentation strategies with an optimal distribution of the consonant within the syllable boundaries (i.e., sonorant coda – obstruent onset), which therefore respected *the syllable contact law* (e.g., Murray & Vennemann, 1983).

Although the 8-year-old children systematically underperformed compared to the participants from the other groups, this is neither a compelling enough finding to allow us to rule out the possibility that they possess a robust sensitivity to sonority-related markedness, on the one hand, nor an argument enabling us to discount the idea that their perceptual and phonological systems are not tuned to reformat phonological sequences that they have never encountered into attested, well-formed ones, on the other. However, we dismiss the possibility that the 8-year-old children's performance might have been due to poor phonological awareness, something which naturally emerges through implicit oral language experiences and underpins the ability to perceive, identify and segment sound sequences into smaller units (e.g., syllables > phonemes) or blend them into larger ones (e.g., phonemes > syllables; e.g., Anthony & Francis, 2005). Instead, we assume that 8-year-old children have partial, well-established phonological abilities that enable them to detect and phonologically repair unattested, ill-formed C_1C_2 onset clusters, in particular by inserting a vowel that reformats the unattested, ill-formed structures as a universally optimal syllable structure. If 8-year-old children do not possess full, finely-honed phonological abilities, this strengthens the idea that weak phonological abilities prevent them from segmenting and counting syllables efficiently.

5. Conclusion

Our findings therefore have important implications by demonstrating that markedness should not be underestimated since it reflects response patterns observed in recent studies involving non-syllable-timed languages, including research in which no output was required (we were particularly careful to avoid articulatory outputs such as sub-vocal repetition in children). This suggests the possibility that markedness might not be restricted only to *explicit* speech production, but that it might also apply to speech perception, maybe in an *implicit*, silent way (see also Berent et al., 2009). It also casts some doubt on the hitherto uncontroversial role of coarticulation or phonotactic – transitional – probabilities in speech segmentation. But it has to be admitted some alternatives that might provide lexical and statistical arguments. Indeed, although our onset clusters were unattested in word-initial position, some had positional and transitional probabilities that were susceptible to influence their retrieval in the lexicon (e.g., /ʌb/ is unattested in onset position but is attested within syllable boundaries). Also, it is conceivable that the misperception of our unattested onset clusters, which were also unattested whatever their position, results from some features sharing that we did not consider and to be compared with attested featurally similar clusters to receive lexical and statistical supports (e.g., /vʌ/ for /zʌ/ in /vʌkij/, *spin*; for more details, see the *Maximum Entropy Model* proposed by Hayes & Wilson, 2008). Our results also imply that the misidentification and repair processes cannot be unquestioningly attributed to failures in the decoding or recoding of acoustic-phonetic contrasts (also see Berent et al., 2012b, for similar conclusions; Davidson, 2011, for counter-arguments). When the participants were requested to pay attention to acoustic-phonetic details within the C_1C_2 onset clusters, sonority-related markedness did not cause a distinction between ill- and well-formedness to misreport an illusory epenthetic vowel. This finding is consistent with Berent et al.'s earlier data (e.g., Berent et al., 2007; 2012b) and lends added support to the hypothesis that misperception and repair might originate in an active universal phonological process. Although our results suggested that sonority-related markedness might take primacy over both perception and repair processes, we naturally do not deny their respective roles or to exclude the possibility that the articulatory gestures that shape universal phonological knowledge might have a role to play. However, we do want to draw attention to the fact that sonority-related markedness may be a foreground factor that, at least partly, determines speech segmentation. Our future research will therefore have to focus on sonority-related markedness within coda clusters or syllable boundaries, which is known to be reverse (i.e., *syllable contact law*; e.g., Murray & Vennemann, 1983). Such a research perspective will make it possible to further investigate whether the perceptual confusion relies on sonority-related markedness or on the identification of acoustic-phonetic cues, in particular since it has been suggested that the SSP is phonetically-grounded, i.e., learnt from experience and based on underlying conditions that govern speech production and perception and are shared by all languages and experienced by all speakers (e.g., Davidson, 2011; Peperkamp, 2007; Hayes & Steriade, 2004; for counter-arguments, see Clements, 2006).

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Appendix

List of monosyllabic pseudowords as a function of their sonority profile.

/ɸbal/, /ɸzal/, /lval/, /lgal/ (high-fall SP);
/fkal/, /ʒgal/, /mʒal/, /ʃpal/ (low-fall SP);
/pkal/, /tpal/, /bdal/, /vzal/ (plateau SP);
/bzal/, /tfal/, /dval/, /kfal/ (low-rise SP);
/zɸal/, /ʒɸal/, /gmal/, /dmal/ (high-rise SP).

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