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Phonological Restriction Knowledge in Dyslexia: Universal or Language-Specific?

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1. Introduction

Developmental dyslexia is the most studied and well-documented of the specific learning disabilities in school-age children across languages, which reaches from 5-to-17.5% individuals (e.g., Shaywitz & Shaywitz, 2005; Snowling, 2001). There is now a consensus that developmental dyslexia stems from a genetic neurodevelopmental disorder that does not depend on inadequate intellectual or educational backgrounds (e.g., Lyon, Shaywitz, & Shaywitz, 2003; Sprenger-Charolles, Colé, Lacert, & Serniclaes, 2000; Vellutino, Fletcher, Snowling, & Scanlon, 2004). There is considerable evidence for a phonological deficit as the major correlate of language disabilities in dyslexia, which underpins the cognitive disorder (e.g., Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003; Ziegler & Goswami, 2005). However, an outstanding, long-lasting question that remains unclear, even unanswered, is what underlies the phonological deficit in dyslexia (e.g., Ramus, 2001). Three main directions have been proposed to account for the phonological deficit: 1) limited phonological short-term memory; 2) degraded, under-specified or, conversely, over-specified phonological representations; 3) speech perception disorders. However, the degraded, under-specified phonological representation hypothesis that is basically referred to accounts for the dyslexics' phonological deficit has been recently challenged: it has been suggested that the dyslexics' phonological deficit relies on difficulties to store, access, and retrieve the phonological representations (e.g., Ahissar, 2007; Ramus & Szenkovits, 2008; Szenkovits & Ramus, 2005). To date, to reconcile both views, it has been proposed that the phonological deficit results in multi-dimensional difficulties that include difficulties to learn and manipulate the speech units as well as difficulties to store, access, and retrieve the phonological representations (e.g., Snowling, 2001; Ziegler, Castel, Pech-Geogel, George, Alario, & Perry, 2008). Despite this tentative proposal, there is no consensus. Here, I propose to draw an up-to-date portrait of an alternative option that has not been studied so far to disentangle whether another possible source of the phonological deficit in dyslexia may be envisaged: Are dyslexics sensitive to *universal* phonological knowledge?

2. On the possible origins of the phonological deficit

Overall, what the past studies have revealed is that the phonological deficit has no clear-cut well-specified origins. Within the phonological deficit hypothesis, typically, it has been suggested that the core deficit children face is rooted in degraded, under-specified phonological representation (e.g., Boada & Pennington, 2006; Elbro & Jensen, 2005; Snowling, 2001).

In a non-negligible proportion, dyslexics' phonological deficit originates in impairments to process auditory information (i.e., ≈ 50%; Ramus et al., 2003). Typically, to account for the degraded nature of the phonological representations, it has been hypothesized that the dyslexics' perceptual system could not turn to be attuned to the native phonemic categories as shown with impairments in categorical perception (e.g., Adlard & Hazan, 1998; Mody, Studdert-Kennedy, & Brady, 1997; Veuillet, Magnan, Écalle, Thai-Van, & Collet, 2007). The categorical perception refers to the tendency to perceive a sound as a member of a category (e.g., /b/ or /p/). Thus, the variants of the same phoneme within a category are more likely perceived as being similar to each other compared to phonemes from other categories (i.e., /b^h/ is more likely judged as similar to /b/ than /p/ while /p^h/ is more likely judged as similar to /p/ than /b/. Scientifically-speaking, the categorical perception can be described as "the degree to which acoustic differences between variants of the same phoneme are less perceptible than differences of the same acoustic magnitude between two different phonemes" (Serniclaes et al., 2004, p. 337). Indeed, dyslexics have been shown to be impaired the processing of relevant acoustic-phonetic characteristics in their native language such as the voicing (e.g., /ba/ - /pa/; Bogliotti, Serniclaes, Messaoud-Galusi, & Sprenger-Charolles, 2008; Hoonhorst, Colin, Markessis, Radeau, Deltenre, & Serniclaes, 2009; Serniclaes, Sprenger-Charolles, Carré, & Démonet, 2001; Serniclaes, van Heghe, Mousty, Carré, & Sprenger-Charolles, 2004). Lower performances in between-categories perception but higher performances in within-categories perception compared to both chronological age-matched and reading level-matched controls have been interpreted as an allophonic mode of speech perception[1]. In other words, dyslexics have difficulties to discriminate two phonemes that belong to two different categories as determined by the voicing (i.e., /ba/ vs. /pa/; low between-boundaries performance) whereas they can discriminate two variants of a same phoneme even if one of the variant does not exist in the native language (e.g., /p/ and /p^h/; high within-boundaries performance). Hence, dyslexics' phonological representations would be over-specified since dyslexics would maintain acoustic-phonetic contrasts that are irrelevant in their native language and should be deactivated early in life (e.g., Saffran, Werker, & Werner, 2006; Werker & Tees, 1984). To be unable to discriminate relevant acoustic-phonetic duration-based contrasts in their native language (i.e., voicing; e.g., /b/ vs. /p/) would induce degraded, under-specified phonological representations and subsequent difficulties to use grapheme-to-phoneme correspondences (e.g., Bogliotti et al., 2008; Serniclaes et al., 2004). Alternatively, the phonological deficit could stem from difficulties in the time-course aspects of pre-lexical phonetic-phonological processing rather than from impaired phonological-lexical representations (e.g., Blomert, Mitterer, & Paffen, 2004; Nittrouer, 1999).

To determine whether the dyslexic's perceptual system is tuned to process finely-sharpened universal phonological representations (i.e., sound sequences that respect or not the

[1] An allophone is a contextual variant of a same phoneme which may be not distinguished within a same phonemic category (e.g., /r/ and /ʁ/ in French). For instance, in French, replacing /r/ with /ʁ/ in /pri/ 'price' will not change its meaning while replacing /r/ or /ʁ/ with /l/ will, i.e., /pli/ , wrinkle'. Allophones are language-dependent.

universal phonological well-formedness), I here envisage the universal phonological sonority-related *markedness* to provide further arguments on the origin of the dyslexics' phonological deficit: universal or language-dependent and degraded/under-specified phonological representations or difficulties to access them?

3. Why the phonological grammar is of interest?

3.1 A phonological grammar?

Native phonological knowledge includes a phonological grammar that embeds language-specific phonemes and phonotactic restrictions that constrain the co-occurrence of sound sequences to perceive and produce sentences (e.g., de Lacy, 2007). In normally-developing newborns and adults, this is a well-known phenomenon that listeners tend to misperceive and repair phonotactically-illegal sound sequences in their native language. Given that the perceptual system becomes, early-on, attuned to sounds and phonotactic restrictions relevant to the native language (e.g., Jusczyk, Friederici, Wessels, Svenkerud, Jusczyk, 1993; Kuhl, Andrusko, Chistovich, Chistovich, Kozhevnikova, Ryskina, Stolyarova, Sundberg, Lacerda, 1997), it has been argued that the perceptual repair could result from: 1) a perceptual assimilation of acoustic-phonetic properties of nonnative sound sequences into native ones or to the phonetically-close ones (e.g., /dla/ in /gla/; in English: Best, 1995; in French: Hallé, Seguí, Frauenfelder, & Meunier, 1998); 2) a compensation for coarticulation since sound sequences such as /dla/ are more difficult to perceive and articulate than /gla/ (e.g., Wright, 2004); 3) a perceptual fit to the phonotactic probablities (e.g., Bonte, Mitterer, Zellagui, Poelmans, & Blomert, 2005); 4) an *illusory epenthetic vowel*; an epenthesis may be a consonant or a vowel present in the phoneme inventory of a target-language, which is inserted to restore a native phonotactically-legal sound sequence (e.g., /dəl/ in English: Berent, Steriade, Lennertz, & Vaknin, 2007; /buz/ in Japanese: Dupoux, Kakehi, Hirose, Pallier, & Mehler, 1999; /dil/ in Portuguese: Dupoux, Parlato, Frota, Hirose, & Peperkamp, 2011). However, in dyslexic adults or children, data remain rare, and focus on phonotactic probabilities (e.g., Bonte, Poelmans, & Blomert, 2007) or, recently, on compensation for place assimilation (e.g., Marshall, Ramus, & van der Lely, in press) and voicing assimilation (e.g., Szenkovits, Darma, Darcy, & Ramus, submitted). Ramus and collaborators thus showed that French dyslexics assimilated phonotactically-illegal sound sequences into phonotactically-legal ones to the same extent as controls. This suggests that dyslexics are able to normally acquire native phonological grammar, and questions the degraded phonological grammar and representations (for counter-arguments, see Bonte et al., 2007).

3.2 An unexplored alternative

As hypothesized within the Optimality Theory framework (Prince & Smolensky, 1993; 1997; 2004), sound sequences that are phonotactically-illegal clusters such as /ʁb/ are more likely rejected compared to phonotactically-legal clusters such as /bʁ/ since all speakers are supposed to have universal phonological knowledge on grammatical restrictions irrespective to their (acoustic-)phonetic properties and phonotactic probabilities. However, whether dyslexics have universal phonological knowledge on grammatical restrictions remain unexplored.

3.2.1 Phonological *markedness* and sonority profile

Phonotactic restrictions straightforwardly rule how sound sequences co-occur. It has been shown that sound sequences depend on the sonority of phonemes (e.g., Clements, 1990). Sonority is a scalar acoustic-phonetic property that refers to the sound's "[…] loudness relative to that of other sounds with the same length, stress, and pitch" (Ladefoged, 1975, p. 221). Under this definition, Fig. 1 presents that sonority hierarchically ranks consonants from the high-sonority phonemes (i.e., from liquid to nasal) to low-sonority ones (i.e., from fricative, /f/, /z/, /ʃ/… to occlusive, /b/, /t/, /g/…). Also, the linguistic structures are supposed to conform to a sonority-based organization as proposed by the *sonority sequencing principle* (e.g., Clements, 1990; Selkirk, 1984): syllables favor a structure with an onset maximally growing in sonority towards the vowel and falling minimally to the coda. Hence, universally-optimal CV syllables that bear high-sonority onsets (e.g., /la/) tend to be avoided in the phonotactics of languages to favor low-sonority ones (e.g., /ta/) whereas, in syllables that do contain a coda, high-sonority codas (e.g., /al/) tend to be preferred to low-sonority ones (e.g., /at/; see Selkirk, 1984). Using a sonority-based distribution of syllables which combines the sonority and the sonority sequencing principle, it is possible to assess the universal phonological knowledge on grammatical restrictions.

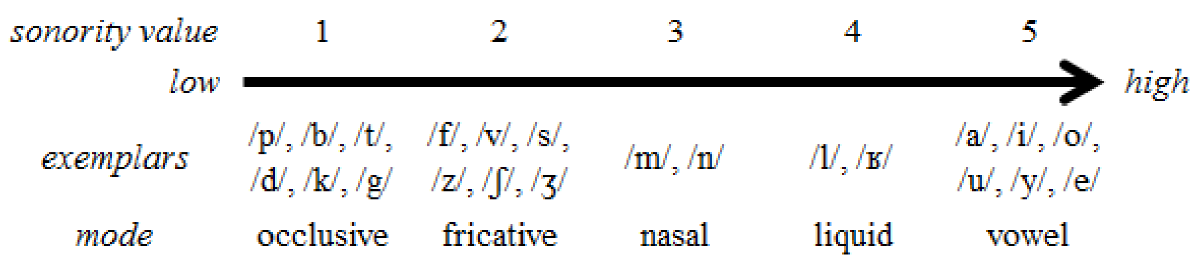

Fig. 1. Sonority scale adapted from Clements (1990) and Selkirk (1984).

3.2.2 Sonority-related *markedness* as a universal phonological knowledge

As proposed within the Optimality Theory framework (Prince & Smolensky, 1993; 1997; 2004), all listeners undergo universal *markedness* and *faithfulness constraints*. Markedness constraints are phonological grammatical restrictions that disfavor some grammatically ill-formed structures (e.g., /ʁb/) whereas faithfulness constraints are constraints that require mapping the input to the output (e.g., mapping the input /ʁb/ to the output /ʁb/). If the input is grammatically well-formed (e.g., /bʁ/), its acoustic-phonetic properties are faithfully encoded and mapped to the output /bʁ/. But, if the input is grammatically ill-formed (e.g., /ʁb/), the input fails to be faithfully encoded and mapped to the output /ʁb/. Accordingly, a grammatically ill-formed input is recoded as a grammatically well-formed output that could trigger a perceptual confusion (e.g., the insertion of an illusory vowel; i.e., an epenthetic vowel such as /ə/). In the view of the Optimality Theory (Prince & Smolensky, 1993; 1997; 2004), universal low-frequency structures -the grammatically ill-formed ones- (e.g., /ʁb/) that transgress markedness constraints are labeled as *marked* whereas universal high-frequency structures -the grammatically well-formed ones- (e.g., /bʁ/) are labeled as *unmarked*. Thus, onset clusters with a sonority high-rise (e.g., /bʁ/, s = +3) are less marked than onset clusters with a sonority low-rise (e.g., /sm/, s = +1), which are less marked than onset clusters with a sonority plateau (e.g., /kb/, s = 0). Then, onset clusters with a sonority plateau are less marked than onset clusters with a sonority low-fall (e.g., /ft/, s = -1), which are less marked than onset clusters with a sonority high-fall (e.g., /ʁb/, s = -3). Hence, monotically, markedness increases and well-formedness decreases from sonority high-rise (unmarked structures) to sonority high-fall (marked structures).

4. The present study

As I mentioned above, there is plenty of work to refine our understanding of where the phonological deficit comes from. Does the phonological deficit arise from degraded, under-specified phonological representations? If the phonological representations are intact, do dyslexic children have intact universal phonological representations? To provide innovative arguments in speech perception in dyslexia, I designed a preliminary syllable count task to pit the universal phonological knowledge on grammatical restrictions in French dyslexic children. I tested the (mis)perception of marked, grammatically ill-formed unattested onset clusters in French dyslexic compared to chronological age-matched controls and reading level-matched controls. Children were aurally-administered monosyllabic $C_1C_2VC_3$ pseudowords (e.g., /pkal/) and their disyllabic $C_1uC_2VC_3$ counterparts (e.g., /pukal/). All C_1C_2 clusters within monosyllabic pseudowords were constructed by splicing out the /u/. Onset clusters (C_1C_2) were classified as high-fall, low-fall, plateau, low-rise or high-rise.

Given the markedness constraints (i.e., avoid marked, grammatically ill-formed outputs such as /ʁb/) and the faithfulness constraints (i.e., map the input /ʁb/ to the output /ʁb/), the misperception of C_1C_2 clusters should increase as markedness increases. Hence, if perceptual confusion depends on universal markedness-related knowledge as determined by sonority profiles, /gmal/ (high-rise SP, the most marked) should be more misperceived as disyllabic than /pkal/ (plateau SP), which in turn, should be more misperceived than /ʁbal/ (high-fall SP, the least marked) in both chronological age-matched and reading level-matched controls. However, since dyslexics are supposed to have degraded, under-specified phonological representations, phonological sonority-related markedness effects and phonological repair with an illusory epenthetic vowel should not be observed.

5. Experiment 1

5.1 Method

5.1.1 Participants

Five French dyslexic children with no comorbid attention deficit hyperactivity disorder (ADHD) were tested in this experiment. Dyslexic children were compared to five chronological age-matched controls and five reading level-matched controls. Control children were recruited from an urban public elementary school. All children were tested after parents returned a consent form. Dyslexic children were diagnosed as dyslexics around two years prior this experiment (M = 29 months; SD = 4 months) by a speech and language therapist. All children were French native speakers with no second language learning, middle class, and right-handed[2]. They reported no hearing disorders. Reading level and IQs

[2] Children's right-handedness was assessed with the Edinburgh Handedness Inventory (Oldfield, 1971) and all scored between +0.80 and +1.

were assessed prior to the experiment. Student *t* tests confirmed that verbal and performance IQs significantly differed between dyslexics and chronological age-matched controls, $t(8) = -3.96$, $p < .005$, $t(8) = 3.10$, $p < .02$ respectively; they also differed on reading level, $t(8) = 9.09$, $p < .0001$, but did not differ on chronological age, $p > .1$. Chronological age significantly differed between dyslexic children and reading level-matched controls, $t(8) = 8.71$, $p < .0001$; neither reading level nor verbal and performance IQs significantly differed, $p > .1$.Chronological age as well as reading level and verbal IQ significantly differed between chronological age-matched and reading level-matched controls, $t(8) = 8.92$, $p < .0001$, $t(8) = 10.56$, $p < .0001$, $t(8) = 2.33$, $p < .05$, respectively. Difference was marginally significant for the performance IQ, $t(8) = 2.01$, $p < .08$. Our research was approved by the Regional School Management Office. Profiles are presented in Table 1[3].

Group	*N* (boys/girls)	Chronological age	Range	Reading level	PIQ	VIQ
Dyslexic children	5 (4/1)	138.0 (5.1)	11;5-12;0	101.4 (6.1)	97.8 (2.9)	95.2 (4.8)
Chronological age-matched controls	5 (3/2)	137.2 (4.3)	10;11-11;10	133.4 (5.0)***	105.8 (5.0)*	107.4 (4.9)**
Reading level-matched controls	5 (5/0)	101.2 (7.9)***	7;7-9;2	102.4 (4.2)	100.0 (4.1)	101.2 (3.3)

Table 1. Chronological and reading level ages, range, verbal and performance IQs for dyslexic children, chronological age-matched, and reading level-matched controls.

5.1.2 Stimuli

Forty stimuli were selected. They were twenty monosyllabic $C_1C_2VC_3$ pseudowords and their disyllabic $C_1uC_2VC_3$ counterparts, which shared their VC_3 rhyme (i.e., /al/) but differed on the structure of their C_1C_2 clusters (Table 2). Onset clusters were unattested in French. I subdivided them into five sonority profiles (SPs) as follows: high-fall (e.g., /ʁbal/), low-fall (e.g., /fkal/), plateau (e.g., /pkal/), low-rise (e.g., /kfal/), and high-rise (e.g., /zʁal/). Onset cluster markedness progresses from high-fall SPs (the most marked, the grammatically worst ill-formed) to high-rise SPs (the least marked, the grammatically most well-formed). Each SP contained four different C_1C_2 clusters, repeated eight times within each SP; overall, there were 4 C_1C_2 x 5 SPs x 8 repetitions x 2 conditions (mono- and disyllabic pseudowords) = 320 stimuli. To exclude some possible phonological biases such as compensation for assimilation or coarticulation, I did not include homorganic consonants (i.e., consonants that share the same place of articulation) and consonants that differ in voicing within C_1C_2 onset clusters. However, C_1 and C_2 could differ in mode of articulation. Disyllabic $C_1uC_2VC_3$ counterparts were recorded by a female native speaker of French. All sounds were digitally recorded with a Sennheiser e865s microphone through a Tascam US-144MK II external audio interface, sampled at a 44 kHz rate, converted with a 16-bit resolution, and bandpass filtered (0 Hz to 5,000 Hz). C_1u first syllable in disyllabic pseudowords systematically carried stress. Monosyllabic $C_1C_2VC_3$ pseudowords were

[3] Note: *N*: number of participants; chronological and reading level ages are in months; ranges are years, months; standard deviations within parentheses; significant difference with dyslexic children: *** $p < .0001$, ** $p < .005$, * $p < .02$; Reading level as determined by the Alouette test (Lefavrais, 1967); PIQ as measured by Raven's Progressive Matrices for French children (PM 38; Raven, 1998); VIQ as measured by WISC-III for French children (Wechsler, 1996).

obtained by splicing out step-by-step the vowel /u/ with Praat software (Boersma & Weenink, 2011). Visual and auditory inspection of the waveforms minimized the /u/ coarticulation-based traces in the C_1 and C_2. Mean duration was 197.3 ms (*SD* = 16.1) for the C_1C_2 clusters and 79.8 ms (*SD* = 11.2) for the vowel /u/.

Sonority profiles				
high-fall	low-fall	plateau	low-rise	high-rise
/ʁbal/,	/fkal/,	/pkal/,	/bzal/,	/zʁal/,
/ʁzal/,	/ʒgal/,	/tpal/,	/tfal/,	/ʒʁal/,
/lval/,	/mʒal/,	/bdal/,	/dval/,	/gmal/,
/lgal/	/ʃpal/	/vzal/	/kfal/	/dmal/

Table 2. Monosyllabic pseudowords used as a function of sonority profiles.

5.1.3 Procedure

This experiment was designed, compiled and run using E-Prime 2.0 Professional software (Schneider, Eschman, & Zuccolotto, 2002) on Sony X-series laptop computers under Windows 7 OS. Children wore Sennheiser HD 25-1 II headphones (16 Hz-22 kHz range, 70 Ω impedance) and were presented pseudowords binaurally at 70 dB SPL. Trials consisted in the presentation of a vertically-centered exclamation mark (i.e., '+') for 500 ms, followed after a 200-ms blank screen by a pseudoword. A 1,000-ms delay separated two consecutive trials. Children were requested to decide as quickly and as accurately as possible whether the pseudoword had one or two syllables (numpad 1 = one syllable, numpad 2 = two syllables). Children were first trained with a practice list of 16 trials with corrective feedback. No feedback was given for the experimental trials. Trials were randomized. The software automatically recorded response times and response accuracy.

5.2 Results

I report first the results from two 5 x 2 x 3 mixed-design repeated measures ANOVAs with Statistica software by subject (*F*1) and by item (*F*2) on response times and response accuracy (~ 84.1% of the data). ANOVAs were run with Group (dyslexics vs. chronological age-matched controls vs. reading level-matched controls) as between-subject factor and Sonority profile (high-fall vs. low-fall vs. plateau vs. low-rise vs. high-rise) and Syllable structure (monosyllabic vs. disyllabic) as within-subject factors.

The d' (Tanner & Swets, 1954) was calculated to assess the discrimination sensitivity threshold. Student t tests on the d' computed for each group show that the discrimination sensitivity threshold does not differ between dyslexic children (M = 1.94, SD = 0.12), chronological age-matched controls (M = 2.18, SD = 0.18) and reading level-matched controls (M = 1.92, SD = 0.27), $p_s > .1$. No children had a $d' = 0 \pm 5\%$ (i.e., random responses). The β, which estimates the criterion decision, did not differ between children, $ps > .1$. Response times and response accuracy were correlated in dyslexic children, $r = -.68$, $t(4) = -3.30$, $p < .006$, in chronological age-matched controls, $r = -.73$, $t(4) = -4.02$, $p < .001$, and in reading level-matched controls, $r = -.72$, $t(4) = -3.88$, $p < .008$.

The analysis revealed a significant main effect of Group in response times only, $F1(4, 48) = 40.09$, $p < .0001$, $\eta^2_p = 0.62$, $F2\ (4, 310) = 31.21$, $p < .0001$, $\eta^2_p = 0.36$; indicating that dyslexic children (1,759 ms) were systematically slower to respond compared to chronological age-matched controls (1,213 ms) and reading level-matched controls (1,509 ms), $t(8) = 29.11$, $p < .0001$, $t(8) = 13.46$, $p < .001$, respectively.

The Sonority profile x Syllable structure interaction was significant in response times (Fig. 2), $F1(4, 48) = 40.09$, $p < .0001$, $\eta^2_p = 0.62$, $F2\ (4, 310) = 31.21$, $p < .0001$, $\eta^2_p = 0.36$ and response accuracy (Fig. 3), $F1\ (4, 48) = 32.69$, $p < .0001$, $\eta^2_p = 0.73$, $F2(4, 310) = 28.55$, $p < .0001$, $\eta^2_p = 0.29$. Fisher's LSD post-hoc tests (Bonferroni's adjusted α-level for significance, $p < .001$) revealed that responses to more marked onset clusters with high-fall SPs (e.g., /ʁbal/) were slower and less accurate relative to the less marked onset clusters with plateau SPs (e.g., /pkal/), which in turn, were slower and less accurate than high-rise SPs (e.g., /gmal/). Responses to low-fall SPs (e.g., /fkal/) were slower and less accurate than low-rise SPs (e.g., /kfal/). Responses to disyllabic counterparts of grammatically worst ill-formed onset clusters with high-fall SPs (e.g., /ʁubal/) were faster and more accurate relative to disyllabic counterparts of less marked onset clusters with plateau SPs (e.g., /pukal/), which in turn, were faster and more accurate than high-rise SPs (e.g., /gumal/). Responses to low-fall SPs (e.g., /fukal/) were faster and more accurate than low-rise SPs (e.g., /kufal/).

Neither the Group nor the Syllable structure main effects were significant in response accuracy. The three-way Sonority profile x Syllable structure x Group interaction did not significantly interact in response times, $Fs < 1$, $p > .1$ and response accuracy, $Fs < 1$, $p > .1$.

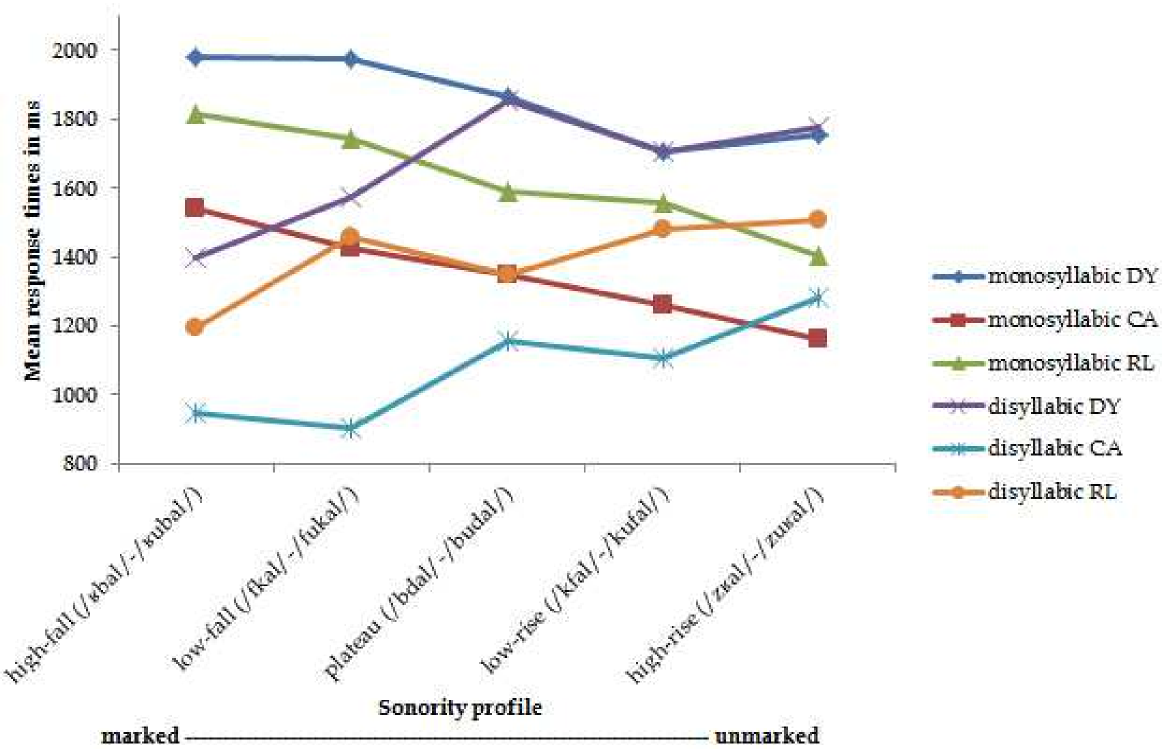

Fig. 2. Mean response times (in ms) to the Sonority profile x Syllable structure interaction for the dyslexic children (DY), chronological age-matched controls (CA) and reading level-matched controls (RL).

To ensure that the perceptual confusion response patterns are not due to coarticulation-based artifacts relative to traces of spliced /u/ from the C_1uC_2 clusters, I examined the nature of the misperception *a posteriori*. Dyslexic children as well as controls were post-tested. Children were asked to report whether or not they heard a vowel, and if so, which one, within monosyllabic pseudowords (n = 160). The task was quite similar, except that for each error, a visual feedback was displayed and children were therefore asked to press on the vowel they thought they heard (i.e., /a/, /i/, /u/, /o/, /e/, /ɛ/, /y/, /ə/, or not a vowel). Response patterns showed that when French dyslexic children misperceived the C_1C_2 clusters, they reported an epenthetic /ə/ ($M = 80.0 \pm 4.4$) more frequently than other vowels ($M = 3.5 \pm 4.7$), $t(4) = 24.69$, $p < .0001$). Response patterns were similar in chronological age-matched controls ($M = 83.9 \pm 5.5$ vs. $M = 5.8 \pm 2.9$, $t(4) = 18.37$, $p < .0001$) and in reading level-matched controls ($M = 81.7 \pm 6.2$ vs. $M = 2.6 \pm 3.8$, $t(4) = 27.00$, $p < .0001$).

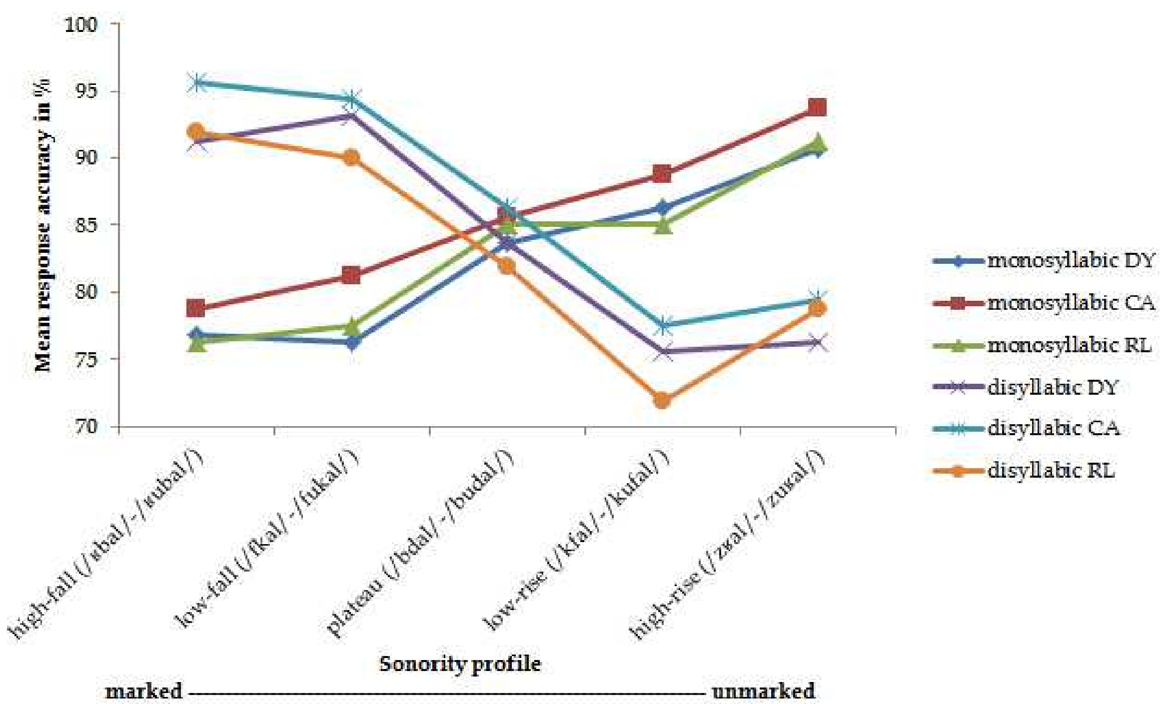

Fig. 3. Mean response accuracy (in %) to the Sonority profile x Syllable structure interaction for the dyslexic children (DY), chronological age-matched controls (CA) and reading level-matched controls (RL).

As in the Berent et al.'s studies (2007; 2008), I submitted children' response accuracy to the C_1C_2 clusters to a linear hierarchically-forced stepwise regression analysis[4]. I first forced in the C_1C_2 cluster length (in ms); then, I forced in the statistical properties of biphones and triphones respectively (I considered C_1VC_2 triphones with a vowel /ə/ that was the most reported epenthetic vowel in children), the bigram frequency (Peereman, Lété, & Sprenger-Charolles, 2007), and the phonotactic transitional probabilities (Crouzet, 2000). The analysis revealed that markedness, which was entered last, accounts for significant unique variance in dyslexic children (Adjusted $R^2 = .276$, $p < .0001$, $\beta = .62$),, chronological age-matched

[4] I used the statistical properties extracted from an oral frequency-based database in French (Gendrot, 2011).

controls (Adjusted $R^2 = .258$, $p < .005$, $\beta = .55$) and reading level-matched controls (Adjusted $R^2 = .394$, $p < .0001$, $\beta = .76$).

6. Discussion

As can be seen throughout this chapter, the dyslexics' phonological deficit has unresolved issues. However, the degraded, under-specified phonological representation hypothesis as a failure in the perception of finely-sharped acoustic-phonetic cues appears to be somehow misleading (e.g., Ramus & Szenkovits, 2008). To solve the intricate problem of the nature of the dyslexics' phonological deficit, I tried to assess whether -and how- the phonological representations are difficult to be accessed, either language-specific or universal, in French dyslexic children compared to chronological age-matched and reading level-matched controls.

The results provide major, innovative responses to a twofold debate: about the nature of the phonological deficit in dyslexics and about the universal phonological knowledge on grammatical restrictions. Crucially, I first observed that the (mis)perception of unattested onset clusters relies on universal sonority-related phonological knowledge on grammatical restrictions. Indeed, response patterns indicate a markedness-modulated misperception of monosyllabic pseudowords as disyllabic ones: as markedness increased from high-rise SP to high-fall SP, perceptual confusion was prone to increase. Also, response patterns were reversed to their disyllabic counterparts: as markedness increased, perceptual confusion decreased. Furthermore, there was no speed-accuracy trade-off: as response accuracy increased, response times decreased.

A posteriori measures confirmed that monosyllabic pseudowords were not perceptually-confused due to coarticulation-based artefacts relative to traces of the spliced vowel /u/: monosyllabic pseudowords are more likely phonologically-repaired with an illusory epenthetic vowel /ə/. Since the vowel /ə/ represents a high-frequency vowel in French, a linear hierarchically-forced stepwise regression analysis discarded a straightforward influence of statistical properties and acoustic-phonetic cues on the misperception and the phonological repair by an illusory epenthetic vowel. Neither the C_1C_2 cluster length, nor the frequency of biphones and triphones explain our results: sonority-related markedness accounts for significant unique variance.

Surprisingly, Group effects were absent; French dyslexic children were as sensitive as both chronological age-matched and reading level-matched controls to the phonological sonority-related markedness of C_1C_2 onset clusters and, as well as controls, they phonologically repaired unattested marked C_1C_2 clusters into attested unmarked ones with an epenthetic /ə/ vowel: this is in accordance with recent results of Maïonchi-Pino, Yokoyama, Takahashi, Écalle, Magnan, & Kawashima (2011) in French adult native speakers (in English, also see Berent et al., 2007; 2008). Of interest, dyslexic children did not differ from both control groups on their response accuracy and discrimination sensitivity threshold (*d'*); however, response times were slower. This suggests that dyslexic children have normal, intact universal phonological constraints and robust phonological representations of their native language; they are able to efficiently recode grammatical ill-formed sequences (i.e., to do that, children insert an epenthetic vowel /ə/ that tends to restore an attested, grammatical well-formed, phonological sequence) and universal phonological representations to avoid a transgression of grammatical well-formedness of phonological sequence. Thus, the children' misperception of marked onset clusters could be attributed to universal phonologically-constrained preferences that follow sonority-related markedness constraints. Since sonority-related markedness relies on acoustic-phonetic cues that might require efficient abilities to perceive, store and process brief acoustic-phonetic information (e.g., Hayes & Steriade, 2004; for counter-argument on the phonetic basis of sonority, see Clements, 2006), and since dyslexic children are as sensitive as controls to this phonological marker, our results compete to reconsider the degraded, under-specified phonological representation hypothesis to further explore the phonological access deficit hypothesis (e.g., Ramus & Szenkovits, 2008).

7. Conclusion

Dyslexic children therefore have intact universal phonological sonority-related sensitivity and efficient language-dependent abilities to underlie both the (mis)perception of phonotactically-illegal clusters and the phonological repair processes, respectively. Further, acoustic-phonetic cues as well as statistical properties do not exhibit straightforward influence, but I do not discard that both contribute to the markedness-related misperception. Further, in our experiment, it remains unresolved whether Peperkamp's position (2007, p. 634-635) is true: "the role of the grammar in phonological perception is not to repair phonologically illegal structure but rather to undo the effect of native phonological processes, and that perceptual repairs take place at a lower, phonetic, processing level". Although I acknowledge that extensive research is important to refine our results, I point out that, as suggested by Ramus & Szenkovits (2008) or Szenkovits et al. (submitted) dyslexics' phonological deficit accommodates with a deficit in storing and accessing the phonological representations.

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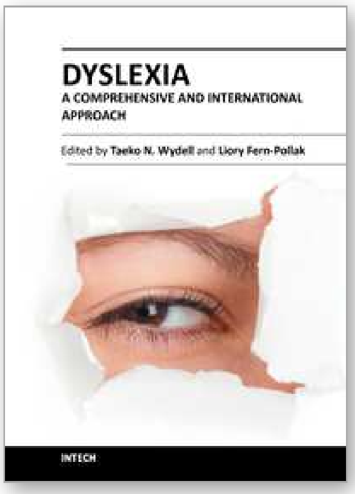

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