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Dyslexia subtypes in languages differing in orthographic transparency: English, French and Spanish

Subtipos de dislexia en lenguas que difieren en la transparencia ortográfica: inglés, francés y español

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The existence of dissociated profiles in developmental dyslexia (the phonological profile with a selective deficit of the phonological reading route, and the surface profile with a selective deficit of the lexical reading route) versus mixed profiles (with both deficits) remains a major theoretical and clinical issue, along with the prevalence of these profiles and the variation in that prevalence across languages with different degrees of orthographic transparency. These issues are examined in a review of studies conducted in English, French and Spanish in which subtyping was established using either the classical method or the regression method. The most reliable results were those obtained with the classical method: (1) the most prevalent profile is the mixed profile; (2) the prevalence of dissociated profiles differs across languages and measures, phonological profiles being more frequent in the accuracy-based English studies than in the accuracy-based French and Spanish studies, and less frequent in the accuracy-based than in the latency-based French and Spanish studies. These last findings probably reflect a measurement issue, as it is easy to use the phonological reading route in transparent orthographies: in these cases, reading speed must be used to detect phonological deficits. These results are not consistent with the idea that clear-cut subtypes can be detected in developmental dyslexia.

Keywords: Developmental Dyslexia; Subtypes; Orthographic Depth; Phonological Dyslexia; Surface Dyslexia; Mixed Profile; Word-level reading skills; Vocal Response Latency.

La existencia de perfiles disociados en la dislexia evolutiva (el perfil fonológico con un deficit selectivo de la ruta de lectura fonológica, y el perfil superficial con un deficit selectivo de la ruta lexica de lectura) versus perfiles mixtos (con ambos déficits) sigue siendo un asunto fundamental teórica y clínicamente, junto con la prevalencia de estos perfiles y la variación de esta prevalencia entre lenguas con diferente grado de transparencia ortográfica. Estos asuntos son examinados en una revisión de estudios realizados en inglés, francés y español en los que los subtipos se establecieron utilizando bien el método clásico bien el método de regresión. Los resultados más fiables fueron los obtenidos mediante el método clásico: (1) el perfil más prevalente fue el perfil mixto; (2) la prevalencia de los perfiles disociados difiere entre lenguas y medidas, siendo los perfiles fonológicos más frecuentes con medidas basadas en la exactitud en los estudios ingleses que en los estudios franceses o españoles, y menos frecuentes en los basados en la exactitud que en los basados en la latencia en los estudios franceses y españoles. Estos últimos hallazgos reflejan problablemente un asunto de medición, dado lo fácil que resulta utilizar la ruta de lectura fonológica en las ortografías transparentes: en estos casos, debe utilizarse la velocidad de lectura para detectar los déficits fonológicos. Estos resultados no son consistentes con la idea de que en la dislexia evolutiva puedan detectarse subtipos claramente definidos.

Palabras clave: Dislexia evolutiva; Subtipos; Profundidad Ortográfica; Dislexia Fonológica; Dislexia Superficial; Perfil Mixto; Habilidades de Lectura a Nivel de la Palabra; Latencia de la Respuesta Vocal.

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The existence of subtypes in developmental dyslexia remains a major theoretical and clinical issue. Most publications in this domain have been based on the dual-route model (Coltheart, Curtis, Atkins & Haller, 1993; Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). In this framework, written words can be processed either through a lexical reading route (also called the orthographic procedure) or a sublexical reading route (also called the phonological procedure). In alphabetic writing, the reading of high-frequency irregular words is generally used to assess the efficiency of the lexical reading route for two reasons: because 1) these words being frequent, they are assumed to be stored in the reader's internal lexicon; and 2) these words being irregular, their processing by the phonological route leads to the production of regularization errors. The reading of new words or "pseudowords" is mainly used to assess the efficiency of the sublexical reading route, because pseudoword reading requires the association between the minimal sublexical units of the spoken language (phonemes) and the minimal sublexical units of the written language (graphemes). Within this framework, dyslexics are classified as *phonological dyslexics* when pseudoword reading is impaired but irregular word reading is spared. They are classified as *surface dyslexics* when irregular word reading is impaired but pseudoword reading is spared. When both pseudoword and irregular word reading are impaired they are classified as having a *mixed profile*. The crucial issues here are the prevalence and the reliability of each of the different subtypes.

Some precautions to take to study developmental dyslexia

The need of multiple-case studies

Group studies and single-case studies were predominant in the research on dyslexia until recently. The goal of group studies is to characterize the phenotypic performance pattern of dyslexics by highlighting what is specific to the information processing of these subjects as a group. The mean scores of a group of dyslexics and a group of average readers are compared, and statistical analyses are used to determine whether they differ significantly on the skills assessed. However, a significant difference between average readers and dyslexics may be due to only a subset of children. For example, the scores of the two groups may differ significantly in pseudoword reading even if only 50% of the dyslexics show evidence of a pseudoword-reading deficit. In group studies, however, the prevalence of the deficits in the skills assessed is usually not considered.

Group studies differ from single-case studies, which look at individuals. The main goal of these studies is to show that it is possible to find "double dissociations" in developmental dyslexia, which could be a significant argument in favor of the dual-route model of reading. However, the question of the prevalence of the different profiles cannot be addressed by single-case studies, since only typical cases with dissociations between lexical and sublexical reading skills (but not mixed profiles) are enrolled in these studies, and only one case.

To assess the prevalence of the various profiles, it is necessary to conduct multiple-case studies that include dyslexics who have not been selected to fit a certain profile, i.e. all dyslexics should be eligible and their individual profiles then investigated. Such studies offer the possibility of overcoming the drawbacks of group and single-case studies. Like single-case studies, multiple-case studies examine individual cases, but they include a number of cases not selected *a priori* for the typicality of their profile. Like group studies, multiple-case studies look at a broad population that is assumed to be representative of the larger population of individuals with dyslexia. As such, they can assess the prevalence of the different profiles.

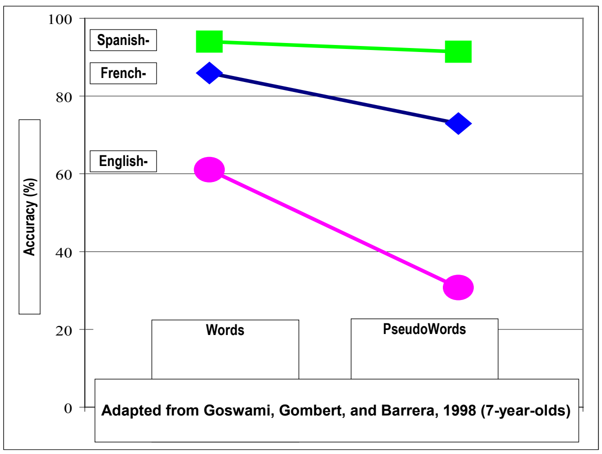
The need for studies based on languages differing in orthographic transparency

The dual-route model has been developed in the context of a language with a deep orthography, namely, English. In such context, it could be useful to develop two independent reading routes, a lexical route for reading irregular word and a sublexical route for reading novel words. Some researchers have questioned the extent to which these two routes develop in transparent orthographies. For example, Share (2008) assumed that "the Coltheart… dual-route model… accounts for a range of English-language findings, but is ill-equipped to serve the interests of a universal science of reading" (p. 584). To assess whether that assumption is or not correct, it is necessary to conduct studies in languages with a shallower orthography than the English orthography, for instance in Spanish or in French.

In French, the level of consistency of grapheme-phoneme correspondences (GPC) is high (Peereman, Lété & Sprenger-Charolles, 2007), and higher than in English (Peereman & Content, 1998), the French orthography being however less consistent than the Spanish orthography (Sprenger-Charolles, 2003 for a comparison between English, French and Spanish). Noteworthy, the rate of reading acquisition mirrors the transparency of the writing system with near-to-ceiling performance of Spanish children after one year of schooling, intermediate performance for French children, and poor performance for English children, especially for pseudoword reading (for reviews, Sprenger-Charolles, Colé & Serniclaes, 2006; Ziegler & Goswami, 2005).

For instance, it a study by Goswami, Gombert, and Barrera (1998), 7-, 8-, and 9-year-old English-, French-, and Spanish-speaking children (matched as closely as possible on reading age) were required to read pseudowords that were similar to words (in English, *tape* versus *fape*; in French, *voile* versus *roile*; in Spanish: *mientes* versus *lientes*). For word reading, the Spanish scores were higher than the French scores, which were higher than the English scores (94%, 86%, and 61%, respectively). The difference between the three linguistic groups was bigger for pseudoword reading (91%, 73%, and 31%). The negative impact of orthographic deepness, and the fact that dissociations between the two reading routes are larger in opaque than in transparent orthographies, is illustrated in Figure 1, which presents the results of the 7-year-old English-, French-, and Spanish-speaking children. Indeed, the more opaque the orthography is, larger is the difference between the reading of words and pseudowords.

Figure 1. Mean accuracy scores for the reading of words and pseudowords by 7-year-old English, French and Spanish children.

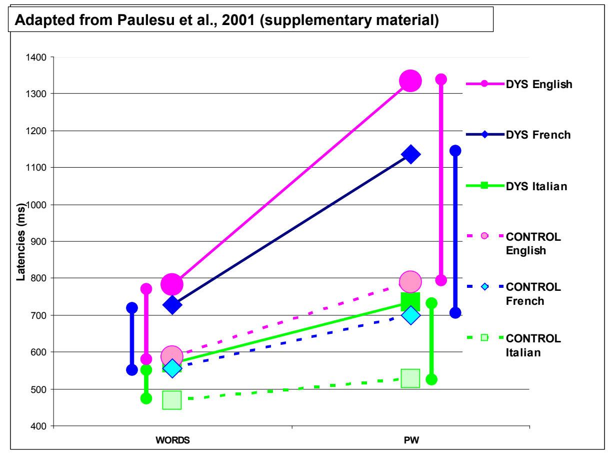


The need for studies that examine both accuracy and speed

An additional issue concerns the nature of the reading outcome measure used. Some dyslexics may perform like average readers on non-timed measures of word and/or pseudoword reading but might show robust speed deficits when reading these words and/or pseudowords. When only accuracy scores are considered, these dyslexics may then be incorrectly considered as having non-impaired word-level reading skills. In addition, as underlined by some researchers (Shaywitz & Shaywitz, 2005), slow processing speed at the word level reflects poorly automated word-level reading skills, the only long-term signature of developmental dyslexia.

These assumptions are supported by a comparison between English-, French- and Italian-speaking adults, either typical readers or dyslexics (Paulesu et al., 2001, supplementary material, Table 1). For word reading accuracy, the scores of the typical readers were at ceiling (in English, French and Italian respectively: 100%, 98.8% and 99.8%) and those of the dyslexics close to the ceiling (97.5%, 97.5% and 99.0%). For reading speed (see Figure 2), even if the absolute values were not directly comparable due to slight differences in hardware and procedure between countries, the results replicated those observed for accuracy by Goswami et al. (1998). It is worth noting that regardless of orthographic opacity, dyslexics' reading impairment compared to typical readers was twice as great for pseudowords as for words. These results suggest that the underlying impairment of English-speaking dyslexics does not differ from that of non-English-speaking dyslexics, being greater when they are required to use the phonological reading route to read words, without the help of their lexical knowledge.

Figure 2. Mean latencies for the reading of words and pseudowords by English, French and Italian adult typical readers and dyslexics.



The above results show that a few milliseconds distinguish the scores of the dyslexics from those of average readers. The measure used to access processing speed must thus be precise. Share (2008, p.593) underlined the fact that the use of vocal response latency (the delay between the appearance of the word on the screen of the computer and the onset of the vocal response) to assess reading speed is a standard practice in the English-language literature but not in regular orthographies, observing that vocal response latencies might be biased by "false starts, self-corrections and hesitations" (p.593). However, vocal response latency has in fact been used in languages with a transparent orthography as well (French: Martin, Colé, Leuwers, Casalis Zorman, & Sprenger-Charolles, 2010; Paulesu et al., 2001; Sprenger-Charolles, Colé, Lacert & Serniclaes, 2000; Sprenger-Charolles, Siegel, Béchennec & Serniclaes, 2003; Sprenger-Charolles, Colé, Béchennec & Kipffer-Piquard, 2005; Ziegler, Castel, Pech-Georgel, George, Alario & Perry, 2008; Spanish: Jiménez, Rodríguez & Ramírez, 2009). In addition, in all but one of these studies (Paulesu et al., 2001), latencies were computed off-line using the speech signal, which makes it possible to listen to the recording and thus to detect false starts, self-corrections and hesitations, the latency of the vocal response in these cases being excluded from analysis.

The need for a developmental framework

It has also been shown that the two reading routes do not develop independently. According to longitudinal data, the sublexical reading route is a bootstrapping mechanism for reading acquisition (for reviews, Share, 1995; Sprenger-Charolles et al., 2006; Ziegler & Goswami, 2005). As a consequence, and given that the dyslexics' sublexical reading skills are generally impaired (Rack, Snowling & Olson, 1992; Stanovich & Siegel, 1994), their lexical reading skills should, it seems, be impaired as well. Therefore, the percentage of mixed profiles (with impairments of both lexical and sublexical reading skills) is assumed to be very high, and little evidence for dissociated profiles (such as surface or phonological profiles) in developmental dyslexia should be found, whatever the opacity of the orthography. However, if there are dissociated profiles, they might be predicted to differ across languages, particularly phonological profiles, since phonological reading skills are easier to acquire in transparent orthographies than in opaque ones, as suggested by the results presented in Figures 1 and 2.

The need for a reading level control group

Another issue in the subtyping literature concerns the control group. The performance of dyslexics is usually compared to that of chronological age (CA) controls. As explained above, the percentage of mixed profiles expected in this comparison is very high, and little evidence for dissociated profiles should be found. For at least three reasons, a comparison with average readers of the same reading level (RL) should also be conducted.

First, reading level has been shown to have an impact on vocabulary size and phonemic awareness (Bryant & Impey, 1986). Thus differences between dyslexics and CA controls in these skills may be merely a consequence of the lower reading level of the dyslexics. Second, there are processing trade-offs in the use of the sublexical and the lexical reading routes that depend on the overall level of word recognition attained (e.g. Backman, Bruck, Hebert & Seidenberg, 1984; Manis, Custodio & Szeszulski, 1993). For instance, in two longitudinal studies with French-speaking children (Sprenger-Charolles et al., 2000; 2003), average readers read pseudowords more accurately than high-frequency irregular words at age 8 but not at age 10 (see Figure 5). Therefore, comparisons of dyslexics with either CA or RL controls are based on skills that differ not only quantitatively but also qualitatively. Finally, dyslexics should be compared to RL controls to investigate whether their developmental trajectory is deviant or delayed. In the later case comparison with RL controls should reveal comparable phonological and orthographic reading skills in the two groups, whereas in the former case, the dyslexics' phonological or orthographic reading skills should be inferior.

The prevalence of dyslexia subtypes

The main goal of this section is to assess the extent to which the prevalence of dyslexia subtypes is the same across studies conducted in three languages that vary in the consistency of GPC: English (Castles & Coltheart, 1993; Manis, Seidenberg, Doi, McBride-Chang & Peterson, 1996; Stanovich, Siegel & Gottardo, 1997), French (Génard, Mousty, Content, Alegria, Leybaert & Morais, 1998; Sprenger-Charolles et al., 2000; Ziegler et al., 2008) and Spanish (Jiménez et al., 2009).

The studies considered have used the same methods to assess the prevalence of the different subtypes: the classical and regression-based methods (a description of these methods is provided below). For the sake of comparability, we have not reviewed studies that did not use both of these methods (e.g. Bowey & Rutherford, 2007; Castles, Datta, Gayan & Olson, 1999; Sprenger-Charolles, Colé, Kipffer-Piquard, Pinton & Billard, 2009). Six of the reviewed studies used irregular word and pseudoword reading as indicators of the reliance on each of the two reading routes. Among these studies, four used only accuracy: the three English studies plus one of the three French studies (Génard et al., 1998). The two other French studies used both accuracy and speed. The speed measure was the latency of each correct response (the delay between the appearance of the word on the computer screen and the onset of the vocal response). Note that the fact that processing speed can only be used when the number of correct responses is not too low (Olson, Forsberg, Wise & Rack, 1994) may explain why in the reviewed studies with English-speaking dyslexic children, only accuracy is considered. In these six studies, the efficiency of the lexical reading route was assessed in the standard way: with irregular words. Because languages with a very transparent orthography do not offer a sufficiently large number of irregular words, we have included a Spanish study in which the efficiency of the lexical reading route was assessed using high-frequency regular word reading (Jiménez et al., 2009) in our review. In that study, as in two out of the three French studies, both accuracy and latency measures were used as outcome variables.

The large number of children involved in those studies should allow us to reliably estimate the prevalence of the different profiles in English, French and Spanish: 172, 130 and 35 dyslexics; 151, 274 and 47 CA controls; and 67, 275 and 40 RA controls (see Sprenger-Charolles, Siegel, Jiménez & Ziegler, 2011, for a detailed presentation of these studies).

Methods used to classify dyslexics

The seven reviewed studies all used both the classical method and the regression method. In the classical method, children are labeled as phonological dyslexics when only their phonological reading skills (assessed with pseudoword reading) are impaired, and surface dyslexics when only their orthographic reading skills (assessed with high-frequency irregular-word reading, except in the Spanish study) are impaired; when both are deficient, they are said to have a mixed profile. In all the reviewed studies, the cutoff for defining a reading skill as impaired is 1 SD below the mean of the controls.

The regression method assesses a relative deficit, either in orthographic skills relative to phonological reading skills, or in phonological reading skills relative to orthographic skills. Stanovich et al. (1997) characterized the subtypes defined in this manner as "soft" as opposed to the "hard" subtypes defined using the classical method. Soft subtypes are defined by plotting pseudoword performance against irregular-word performance (and vice versa) and then examining the 95% (or 90%) confidence intervals (CI) around the regression lines determined from the control group. A phonological dyslexic is a child who is an outlier when pseudowords are plotted against irregular words, as in Figure 3a, but who is in the normal range when irregular words are plotted against pseudowords, as in Figure 3b (e.g. the 8 children who are within the red circles in Figures 3a-3b). A surface dyslexic is defined in the opposite way (e.g. the 3 children who are within the green circles in Figures 3a-3b). A dyslexic whose scores are outside the CI in both cases has a mixed profile (1 case in the example provided: Kim, who is within the black circle in Figures 3a-3b). Finally, a dyslexic whose scores are inside the CI in both cases has no deficit at the level of word reading (e.g. Max and Adele, who are within the black squares in Figures 3a-3b).

Figures 3a-3b. Soft subtypes: Examples of phonological dyslexics, surface dyslexics and mixed profiles (Adapted from Sprenger-Charolles et al., 2000).

Figure 3a. Pseudoword processing time plotted against irregular word processing time for dyslexics (squares). Regression line and confidence intervals (95%) were derived from the data of CA controls (circles). Phonological dyslexics are shown as filled-in squares (for instance, Justine, who is in the red circle in figures 3a-3b), and dyslexics with both deficits as crossed out squares (for instance, Kim, who is in the black circle in figures 3a-3b).

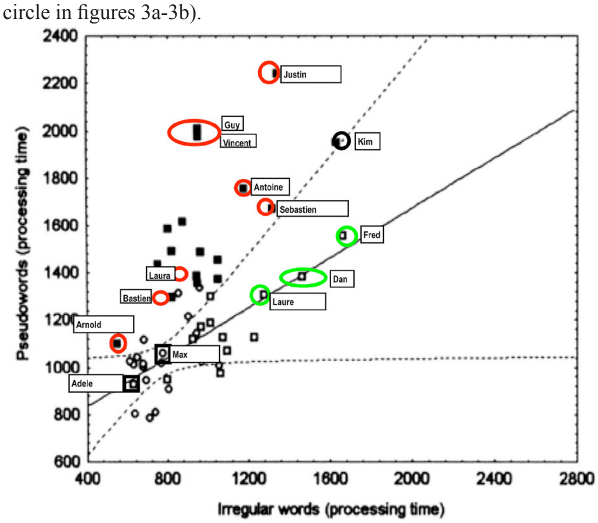
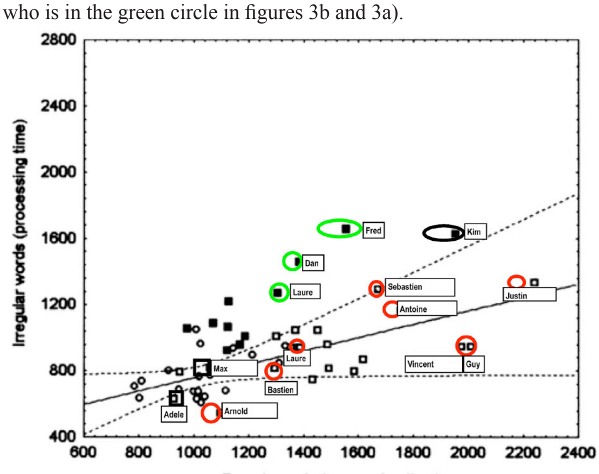


Figure 3b. Irregular-word processing time plotted against pseudoword processing time for dyslexics (squares). Regression line and confidence intervals (95%) were derived from the data of CA controls (circles). Surface dyslexics are shown as filled-in squares (for instance, Fred, who is in the green circle in figures 3b and 3a).

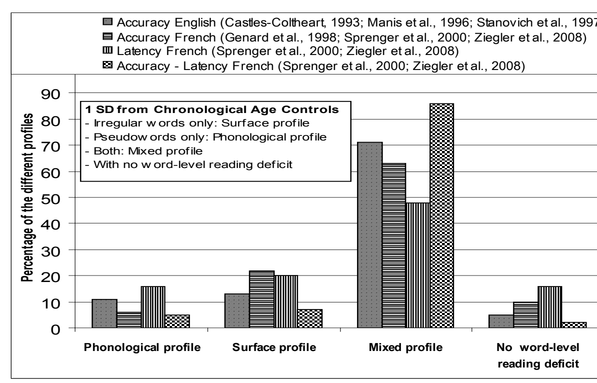


Chronological Age Comparison

Hard subtypes: Classical method.

We first considered only the English and the French samples in which reading scores were 1 SD below (for accuracy) or above (for speed) the mean of the CA controls on pseudowords only (hard phonological profile), high-frequency irregular words only (hard surface profile), pseudowords and irregular words (mixed profile), as well as those with no deficit on either assessment. The results are presented in Figure 4. As expected, mixed profiles were the most common across all studies for either accuracy (71% in English and 63% in French) or speed (data only available for the French group: 48%). When, in the French samples, both accuracy and speed were taken into account, 86% of the dyslexics were classified as having a mixed profile. Finally, a higher proportion of dyslexics with non-impaired word-level reading skills was observed in French (10% for accuracy and 16% for speed) compared to English (5% for accuracy). However, in the French studies where both accuracy and speed were considered almost all the dyslexics were found to have deficient word-level reading skills.

Figure 4. Prevalence of the different profiles in English and in French: Comparison to chronological-age controls.



The results of the Spanish sample are presented along with those of the English and French samples in Table 1. In the former case, the efficiency of the lexical reading route was assessed with the reading of high-frequency regular words. Again, and as expected, mixed profiles were the most common across all studies for both accuracy and speed. In addition, the percentage of hard phonological dyslexics was lower than that of hard surface dyslexics in the accuracy-based French and Spanish studies (6% versus 22% in French, 8% versus 23% in Spanish), but never in the latency-based French and Spanish studies (16% versus 20% in French; 11% versus 14% in Spanish) nor in the accuracy-based English studies (11% versus 13%). Finally, the percentage of dyslexics with non-impaired reading skills was higher in Spanish than in French and higher in French than in English, for accuracy (respectively, 26%, 10% and 5%) and higher in Spanish than in French for speed (20%

versus 16%, no data available in English). However, as already underlined, when both accuracy and speed are taken into account in French (see Figure 4) almost all the dyslexics were found to have deficient word-level reading skills. There are thus cross-language differences (in the proportion of non-impaired readers) and cross-language similarities (in the proportion of mixed profiles) between the three languages studied.

Soft subtypes: Regression-based method.

The subtypes reported here were based on accuracy scores in all but two studies because of ceiling effects (the Spanish study by Jiménez et al., 2009 and the French study by Sprenger-Charolles et al., 2000). The prevalence of the different profiles is presented in Table 1. In contrast to the results of the classical method, those of the regression method indicated a very low proportion of mixed profiles in the accuracy-based English and French studies (respectively, 16% and 2%), as in the latency-based French and Spanish studies (respectively, 2% and 0%). However, unlike the results observed with the classical method, the percentages of each of the two soft-dissociated profiles observed with the regression method varied strongly across studies, and even between studies conducted in the same language (see Sprenger-Charolles et al., 2011). In addition, a significant proportion of dyslexics were found not to have any reading deficit in the latency-based Spanish and French studies (respectively, 31% and 20%). That proportion was higher in the accuracy-based studies: 94% in Spanish (not reported in Table 1) and 41% in French versus 21% in English. The Spanish and French results cast doubt on the validity of the use of accuracy-based measures for classifying dyslexics in consistent orthographies, at least when the regression method is used.

Table 1. Mean percentage (and number) of different subtypes for each language and each measure in the chronological age comparison (hard and soft subtypes) and in the reading level comparison (only soft subtype).

Chronological age comparison: Hard Subtypes *(Cut-off: 1 Standard-Deviation)*

	English (Castles-Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997)		French (Genard et al., 1998; Sprenger et al., 2000; Ziegler et al., 2008)		Spanish (Jiménez et al., 2009)		French (Sprenger et al., 2000; Ziegler et al., 2008)		Spanish (Jiménez et al., 2009)	
	Accuracy scores						Latency for correct responses			
	N = 172		N = 130		N = 35		N = 55		N = 35	
	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number
Phono Dyslexics	11	19	6	7	8	3	16	9	11	4
Surface Dyslexics	13	22	22	28	23	8	20	11	14	5
Mixed Profiles	71	122	63	82	43	15	48	26	54	19
Without Deficit	5	9	10	13	26	9	16	9	20	7

Chronological age comparison: Soft Subtypes (Confidence Interval: 95 for the French studies and for Manis et al. ; 90 for the other studies)

	English (Castles-Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997)		French (Genard et al., 1998; Ziegler et al., 2008)		Spanish (Jiménez et al., 2009)		French (Sprenger et al., 2000; Ziegler et al., 2008)		Spanish (Jiménez et al., 2009)	
	Accuracy scores						Latency for correct responses			
	N = 172		N = 99				N = 55		N = 35	
	Percent	Number	Percent	Number			Percent	Number	Percent	Number
Phono Dyslexics	37	63	7	7			40	22	23	8
Surface Dyslexics	27	46	49	49			38	21	46	16
Mixed Profiles	16	27	2	2			2	1	0	0
Without Deficit	21	36	41	41			20	11	31	11

Reading level comparison: Soft Subtypes (Confidence Interval: 95 for the French studies and for Manis et al.; 90 for the other studies)

	English (Castles-Coltheart, 1993; Manis et al., 1996; Stanovich et al., 1997)		French (Genard et al., 1998)				French (Sprenger et al., 2000)		Spanish (Jiménez et al., 2009)	
	Accuracy scores						Latency for correct responses			
	N = 159		N = 75				N = 31		N = 35	
	Percent	Number	Percent	Number			Percent	Number	Percent	Number
Phono Dyslexics	29	47	8	6			39	12	34	12
Surface Dyslexics	3	4	0	0			10	3	14	5
Mixed Profiles	0	0	0	0			0	0	0	0
Without Deficit	68	108	92	69			52	16	52	18

Reading Level Comparison: Soft subtypes based on the regression method.

One of the aims of the reviewed studies was to examine dissociated profiles. Because (1) the number of dyslexics with a dissociated profile found using the classical method in the CA comparison was low and (2) the number of dyslexics with impaired reading skills decreased from the CA to the RL comparison, the sole means of finding a sufficient number of dissociated profiles in the RL comparison was to use the regression method.

The results are presented in Table 1. Based on accuracy, the percentage of soft phonological dyslexics remained quite high, whatever the language (8% to 29%), whereas soft surface profiles almost disappeared (0% to 3%): among 234 dyslexics, 53 phonological and 4 surface profiles. A similar result was found with speed as the measure (24 phonological profiles and 8 surface profiles among 66 dyslexics). Another noteworthy finding was that the proportion of dyslexics with no deficit in either pseudowords or words was very high, both for accuracy (68% in English, 92% in French) and for speed (52% both in French and in Spanish). Thus, with the regression method, most of the dyslexics have a delayed profile.

Why does the prevalence of the different subtypes vary across languages, methods and measures?

There were five major findings concerning the prevalence of the subtypes. The first two, from comparisons with CA controls, are contradictory: the classical method consistently revealed a high percentage of mixed profiles and a low percentage of dissociated profiles, irrespective of measure (accuracy or speed) or language; the opposite pattern was observed with the regression method. Two other findings are related to the soft-dissociated profiles found in comparisons with RL controls: regardless of language and measure, the percentage of soft phonological profiles remained quite high, whereas soft surface profiles almost disappeared. Finally, cross-language differences were observed in the distribution of the dissociated profiles: for instance, when the classification was based on accuracy scores, the percentages of hard and soft phonological dyslexics were below those of hard and soft surface dyslexics in the French and Spanish studies, but not in the English studies.

Impact of the measure used on subtyping.

The results presented in Figure 4 suggest that both accuracy and speed are needed to classify a child as a dyslexic. Indeed, almost all dyslexics from the French sample have impaired word-level reading skills when both measures are taken into account. This is illustrated by the two children in the black squares in Figures 3a-3b, Max and Adele. Their latencies were within the normal range of the CA controls for both irregular word and pseudoword reading, whereas their accuracy scores were more than 2 SDs away from the control mean (respectively 75.0 versus 70.8 for Max and 75.0 versus 79.2 for Adele). This is also illustrated by the results found for Arnold with the classical method, which are within the normal range for speed, but not for accuracy (83.3% and 75% for irregular words and pseudowords, i.e. 1.8 and 3 SDs from the mean for controls). Therefore, not taking accuracy into account in addition to speed leads to an erroneous classification of these children as non-impaired readers. The reverse is also true. For instance, Laura's accuracy scores are within the normal range (100% for irregular words and 91.7 for pseudowords), but not her latencies (1.3 and 2.4 SDs of the norms).

Impact of the method of classification on subtyping.

A high proportion of dyslexics were found to have no reading difficulties using the regression method. For instance, when the classification was based on accuracy, this percentage was as high as 94% in the Spanish study, as compared to 26% for the classical method. Therefore, as noted by Jiménez et al. (2009, p.10) "accuracy scores are not appropriate for classifying dyslexic subtypes in a consistent orthography," at least when the regression approach is used. This is because that method relies on correlations, which are sensitive to ceiling (and floor) effects: these are common in control data because the tasks used often measure abilities that are well within the competence of non-impaired participants (Crawford & Garthwaite, 2005).

Another problem with the regression method is illustrated by the results presented in Figures 3a-3b, for instance those of Justine, Antoine, Sebastien, Bastien, Arnold, Fred, Dan and Laure. For irregular word and pseudoword reading respectively, the latency scores of Justine, Antoine, Sebastien and Bastien were respectively 4.2 versus 8 SDs, 3.0 versus 4.8 SDs, 4.1 versus 4.2 SDs and 0.3 versus 1.8 SDs away from the mean of the controls. For the same items, the latencies of Fred, Dan and Laure were respectively 6.7 versus 3.5 SDs, 5.2 versus 2.3 SDs and 3.7 versus 1.8 SDs, and those of Arnold were within the normal range. Based on the classical method, six of these children were classified as having a mixed profile, one (Bastien) as a phonological dyslexic and one (Arnold) as a non-impaired reader. Based on the regression method, Arnold was classified as a phonological dyslexic, which is surprising. Justine, Antoine, Sebastien and Bastien were also classified as phonological dyslexics, with non-impaired lexical reading skills, which is clearly wrong, except for Bastien. Fred, Dan and Laure were considered as surface dyslexics with non-impaired phonological reading skills, which is also wrong. Nevertheless, the regression method successfully captured the facts that Justine and Antoine's phonological reading skills were more severely impaired than their orthographic skills (but not those of Sebastien) and that Fred, Dan and Laure's orthographic reading skills were were more severely impaired than their phonological skills. New methods to deal with this issue have been devised (Crawford & Garthwaite, 2005; Crawford, Garthwaite & Gray, 2003).

Another important question is that of the correlations within the normative sample. As Bates, Appelbaum, Salcedo, Saygin and Pizzamiglio (2003) explain, "the number of dissociations we are able to detect is systematically related to the magnitude of the correlations between measures. If the correlation is low (approaching zero) we are able to find a relatively large number of dissociations. However, this is not necessarily a good thing: low correlations may reflect a true and meaningful form of independence between measures, but they may also reflect high measurement unreliability. (…) By contrast, if the correlation between the measures is high, then dissociations are much more difficult to detect" (p.1150). This could explain why there were more individuals with extreme discrepancies between lexical and sublexical reading skills in the study by Castles and Coltheart (1993) compared to the study by Manis et al. (1996): 85% versus 62% (see Appendix 2b in Sprenger-Charolles et al., 2011). Indeed, the correlations between irregular word and pseudoword reading in the dyslexic samples of Castles and Coltheart (1993) and Manis et al. (1996) were respectively .11 and .36.

Impact of orthographic transparency on subtyping.

The results for accuracy indicate that as the degree of the transparency of the orthography increased, so did the proportion of dyslexics without any apparent reading deficit at the word level. Indeed, the Spanish study showed the highest proportion of dyslexics with non-impaired reading skills . In addition to the above explanation, the Spanish results could be due to the fact that the Spanish classification was based on high-frequency regular words. These words could be read by both the lexical and the sublexical reading route, and thus lead to a fewer number of errors than high frequency irregular words. This result has been observed in studies with non-impaired readers and with dyslexics in French (e.g. Sprenger-Charolles et al., 2003; 2009).

Another major finding concerns the systematic differences in the proportion of hard-dissociated profiles across transparent and opaque writing systems. In the accuracy-based Spanish and French studies, surface dyslexics were more frequent than phonological dyslexics. But no such systematic differences between the proportion of phonological and surface dyslexics were obtained in the accuracy-based English studies, nor in the latency based French and Spanish studies. We believe that these findings reflect a measurement *artefact* due to the fact that pseudoword reading in transparent orthographies is much easier than in opaque orthographies; indeed, pseudoword accuracy for dyslexics in transparent languages is often at ceiling (e.g. Jiménez et al., 2009; Martin et al., 2010; Sprenger-Charolles et al., 2000). This does not mean that deficits in phonological reading skills do not exist in transparent orthographies but rather that reading speed has to be used to ensure that such deficits are detected (e.g. in Spanish: Davies, Cuetos, & Glez-Seijas, 2007; Jiménez & Hernández-Valle, 2000; Jiménez et al., 2009; Serrano & Defior, 2008, in French: Martin et al., 2010; Paulesu et al., 2001; Sprenger-Charolles et al., 2000).

Reliability of phonological and surface profiles

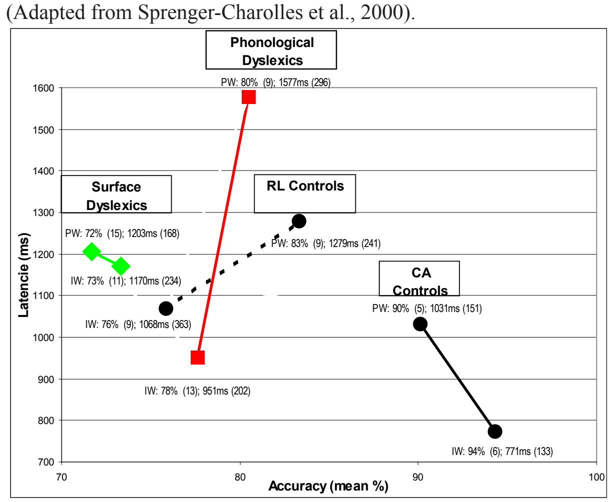
One approach to testing the reliability of a classification is to use "validation measures" that are related to the hypothesized reading deficits but independent of the tasks used to classify the subjects. Such additional evaluations have been conducted in English (Manis et al., 1996; Stanovich et al., 1997), French (Sprenger-Charolles et al., 2000; Ziegler et al., 2008), and Spanish (Jiménez et al., 2009). These evaluations were based on the data from the dyslexic children who exhibited soft-dissociated profiles according to the regression method in the CA comparison (because this is the only possible way to find a high number of dissociated profiles).

Reading skills in phonological and surface profiles

The most significant findings came from the comparison between the two groups of dyslexics with a soft-dissociated profile and RL controls (not considered by Ziegler et al., 2008). Soft phonological dyslexics' phonological reading skills were always inferior those of RL controls, but this was not true of soft surface dyslexics' orthographic skills, except in one study (Jiménez et al., 2009) which found surface dyslexics to be worse than RL controls in a homophone choice task that was designed to assess the efficiency of the lexical route.

For instance, in the French study of Sprenger-Charolles et al. (2000), the two groups of dyslexics with a soft-dissociated profile based on the comparison with CA controls were compared to RL controls on the measure used to define their profiles (irregular word versus pseudoword latency) and on another measure (irregular word versus pseudoword accuracy). The results are presented in Figure 5. Soft surface dyslexics' irregular-word scores were not significantly lower than those of RL controls, nor were those of the soft phonological dyslexics, whether on accuracy or on speed. In sharp contrast, both groups of dyslexics obtained lower scores on pseudoword reading than the RL controls, in terms of speed for the soft phonological dyslexics (measure used to define their profiles) and in terms of accuracy for the soft surface dyslexics (measure not used to define their profiles).

Figure 5. Trade-off between accuracy and speed in dyslexic children and average readers: Chronological age and reading level comprarison (Adapted from Sprenger-Charolles et al., 2000).



Phonological reading-related skills in phonological and surface profiles

Dyslexics difficulties in reading new words are generally explained in terms of their poor phonological skills outside the reading domain, particularly in phonemic awareness and phonological short-term memory (STM). These deficits may hinder the acquisition of the sublexical reading procedure, which requires the ability to connect graphemes with phonemes and to blend the phonemic units together. The first operation requires fully established phonemic categories; the second, adequate phonological STM. A child who is unable to correctly process phonemes, and, in addition, suffers from a deficit in phonological STM, will not be able to make efficient use of the sublexical reading procedure. Deficits in rapid naming are also taken as indicators of a phonological deficiency (Ramus, 2003). Deficits in these phonological reading-related skills are expected to characterize phonological dyslexics but not surface dyslexics.

Among the five studies in which phonemic awareness was assessed, only the two studies with English children found a deficit that was specific to phonological dyslexics (Manis et al., 1996; Stanovich et al., 1997). In contrast, in the Spanish study (Jiménez et al., 2009) both phonological and surface dyslexics' phonemic awareness skills were inferior to those of CA controls. Similarly, in the French-language studies of Ziegler et al. (2008) and Sprenger-Charolles et al. (2000) surface dyslexics exhibited deficits in phonemic awareness tasks that were not significantly different from those of phonological dyslexics. Phonological and visual STM were also assessed by Sprenger-Charolles et al. (2000). A specific deficit in phonological STM was expected for phonological dyslexics, whereas a specific deficit in visual STM was expected for surface dyslexics. In fact, both phonological and surface dyslexics had significantly worse phonological STM, but not visual STM, than CA controls. Finally, in the two studies in which rapid naming was assessed, one study (Jiménez et al., 2009) found both phonological and surface dyslexics to be slower than CA controls and the other (Ziegler et al., 2008) found surface dyslexics to be even slower than phonological dyslexics.

In addition, the three studies that assessed phonemic awareness in Spanish and French (Jiménez et al., 2009; Sprenger-Charolles et al., 2000; Ziegler et al., 2008) found a phonemic deficit not only in phonological dyslexics but also in surface dyslexics. In addition, Sprenger-Charolles et al. (2000) found both phonological and surface dyslexics to lag behind CA controls for phonological STM. Finally, in the two studies which included assessments of rapid naming, both phonological and surface dyslexics were slower than CA controls (Jiménez et al., 2009; Ziegler et al., 2008). Thus, phonological deficits in reading and reading-related skills were observed in surface profiles. Therefore, these profiles appear to be *less reliable* than phonological profiles.

Tentative explanations of phonological and surface profiles

In the RL comparison, the proportion of soft phonological dyslexics remained quite high, whereas the soft surface profile almost disappeared. This finding suggests that the developmental trajectory of phonological dyslexics is *deviant*, whereas that of surface dyslexics is *delayed*. These conclusions are supported by the analyses based on "validation measures." For instance, surface dyslexics' orthographic skills did not differ from those of RL controls, except in the results of Jiménez et al. (2009), a result that could be due to an environmental factor: poor home literacy experience. In contrast, the phonological reading skills of soft phonological dyslexics systematically fell below those of RL controls (e.g. Manis et al., 1996; Sprenger-Charolles et al., 2000; Stanovich et al., 1997).

The claim that the developmental trajectory of the phonological dyslexics is *deviant* whereas that of the surface dyslexics is *delayed* is also supported by the results of studies not included in the present review: for instance, results from multi-case studies (Bowey & Rutherford, 2007; Manis & Bailey, 2008) and from single-case studies (Temple & Marshall, 1983, see Bryant & Impey's re-analyses, 1986; Valdois et al., 2003). Other studies suggest that the surface profile is *less reliable* than the phonological profile. Indeed, phonological deficits have been reported in surface dyslexia (single-case studies: Coltheart, Masterson, Byng, Prior, & Riddoch, 1983, see Bryant & Impey's re-analyses, 1986; multi-case studies: Bailey, Manis, Pedersen, & Seidenberg, 2003; Zabell & Everatt, 2002). For instance, Zabell and Everatt (2002) found surface dyslexics to behave in the same way as phonological dyslexics on four tasks requiring phonological processing, particularly pseudoword reading and phonological awareness. In addition, Bailey et al. (2003) found a tendency in surface dyslexics to score lower than RL controls on pseudoword reading. Longitudinal data also indicate that surface profiles are less stable than phonological profiles (e.g. Manis & Bailey, 2008; Sprenger-Charolles et al., 2000).

One possible explanation is that the surface profile may be due to both a slight phonological impairment and aggravating environmental factors. As suggested by Stanovich et al. (1997; see also Stanovich, 1999), children from a disadvantaged social background may not only be less frequently exposed to written material, but may also be given less help in overcoming their reading deficiency than children from a social environment likely to motivate them to learn to read despite their difficulties. Thus, as also noted by Harm and Seidenberg (1999), the combination of mild phonological deficits and lack of reading opportunities could lead to the surface profile. This account could explain why surface dyslexics are often found to have impaired phonological reading skills in addition to impaired orthographic reading skills, the latter impairment being explained by the fact that the acquisition of well-defined orthographic representations requires frequent exposure to print.

This explanation is supported by the finding of Jiménez et al. (2009) that the orthographic deficit observed in surface dyslexics compared to RL controls was associated with poor home literacy experience. Additional support for this interpretation is reported in Castles et al.'s (1999) large-scale twin study, in which two subgroups of dyslexics with a dissociated profile (approximately 300 surface and 300 phonological dyslexics) were selected among a group of almost 1000 dyslexics. In measures used to assess exposure to print and lexical reading skills, the scores of the surface dyslexics were lower than those of the phonological dyslexics. Examination of the relations between the reading deficits of monozygotic versus dizygotic twins indicated a small but significant genetic component together with a large influence of the environment in surface dyslexics, and the reverse pattern for phonological dyslexics. These results thus support accounts of surface dyslexia that emphasize a strong environmental contribution.

Conclusion

Further progress is needed to allow researchers and clinicians to correctly diagnose cases of developmental dyslexia and its subtypes, especially dissociated profiles. First, the reliability of each of the dissociated profiles must be measured. This should be accomplished through the use of validation measures which are related to the hypothesized deficits but independent of the tasks used to classify the subjects. Secondly, it is necessary to assess the strength of the dissociation in each dissociated profile: that is, the magnitude of the difference between the scores obtained by a dyslexic on tasks measuring lexical reading skills and those measuring phonological reading skills (Bates et al., 2003; Crawford et al., 2003; 2005). Thirdly, both accuracy and speed must be taken into account: assessments which are only based on one of the two measures will lead to misclassifications.

Although dissociated profiles need to be carefully examined, this should not lead us to forget that, overall, the results of the reviewed studies are not consistent with the view that developmental dyslexia is divided into clear-cut subtypes. Instead, they indicate that dyslexia is characterized by difficulties with accurate and/or rapid word-level reading skills that result from phonological deficits, in keeping with a current definition of dyslexia (Lyon, Shaywitz, & Shaywitz (2003).

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