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What phonological deficit?

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We review a series of experiments aimed at understanding the nature of the phonological deficit in developmental dyslexia. These experiments investigate input and output phonological representations, phonological grammar, foreign speech perception and production, and unconscious speech processing and lexical access. Our results converge on the observation that the phonological representations of people with dyslexia may be intact, and that the phonological deficit surfaces only as a function of certain task requirements, notably short-term memory, conscious awareness, and time constraints. In an attempt to reformulate those task requirements more economically, we propose that individuals with dyslexia have a deficit in access to phonological representations. We discuss the explanatory power of this concept and we speculate that a similar notion might also adequately describe the nature of other associated cognitive deficits when present.

How I learned to stop worrying and love the phonological deficit

Back in 1999, as I (FR) started discussing the possibility of a post-doc with Uta Frith, the target clearly was to further investigate the nature of the phonological deficit in dyslexia. This was a field where my background in psycholinguistics might conceivably be of some use. And this was indeed the topic for which I started to work in January 2000.

While thinking about new experiments tapping the phonological deficit, I embarked on a more comprehensive literature review of dyslexia. I discovered the many theories of dyslexia and the difficulties of interpreting the data relative to each theory. I was notably illuminated by Uta's "Paradoxes" paper (Frith, 1999), which, by a judicious use of the causal modelling framework (Morton & Frith, 1995), outlined particularly clearly the various possible theoretical models accounting for any set of behavioural data. One thing that particularly worried me was the presence of auditory deficits in dyslexia. If at least some individuals with dyslexia had auditory deficits, how could I expect them to perform normally in phonological tasks requiring auditory perception of the stimuli, and how would I be able to unambiguously interpret my data? I therefore felt the need to include an auditory task in my test battery, at least as a control. For that purpose I sought the collaboration of Stuart Rosen. It turned out that the choice of the relevant auditory task was not trivial, and different kinds of auditory deficits would be expected to impact on different aspects of phonology. It therefore seemed inevitable to employ a whole battery of various

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auditory tests. This is where the project started going seriously off-track.

The study was looking more like a test of auditory theories of dyslexia. At the same time I didn't want to reproduce the shortcomings that I found in previous studies: that is, to test the predictions of one particular theory of dyslexia and ignore the others (Ramus, 2001a). It seemed a pity to administer such a fine battery of phonological and auditory tests and not to take the opportunity to add visual magnocellular measures and motor/cerebellar tests. Quite rapidly the project got entirely out of control. With the complicity of a few more collaborators, I ended up with a 10-hour test battery. To Uta's great regret and to my great shame, out of 10 hours, less than 1 was actually dedicated to phonological tasks, and rather uninspiring ones.

Uta frequently reminded me of my culpable neglect of the phonological deficit. But she also let me entirely free to pursue my new craze, always providing as much encouragement and critical feedback as was needed. This must be a hallmark of her mentoring style, for which I am immensely grateful. Sometimes I wonder whether she would also have encouraged me to study dyslexia in parabolic flight or under the sea. Perhaps she had somehow foreseen that the project, even if not quite the intended one, would be quite successful in the end (Ramus, Pidgeon, & Frith, 2003a; Ramus et al., 2003b; Ramus, White, & Frith, 2006; White et al., 2006a; White et al., 2006b). The present paper is, at last, about a first significant attempt to get to grips with the phonological deficit.

What we know and what we don't know about the phonological deficit

Phonologists and psycholinguists have described in great detail the structure of phonological representations, the rules (or computations) operating on them, and the various levels of representation and processing that must necessarily be involved in speech perception and production. That area has been reviewed before in relation to dyslexia (Ramus, 2001b). Here we only recall the overall cognitive architecture that we assume (Figure 1),

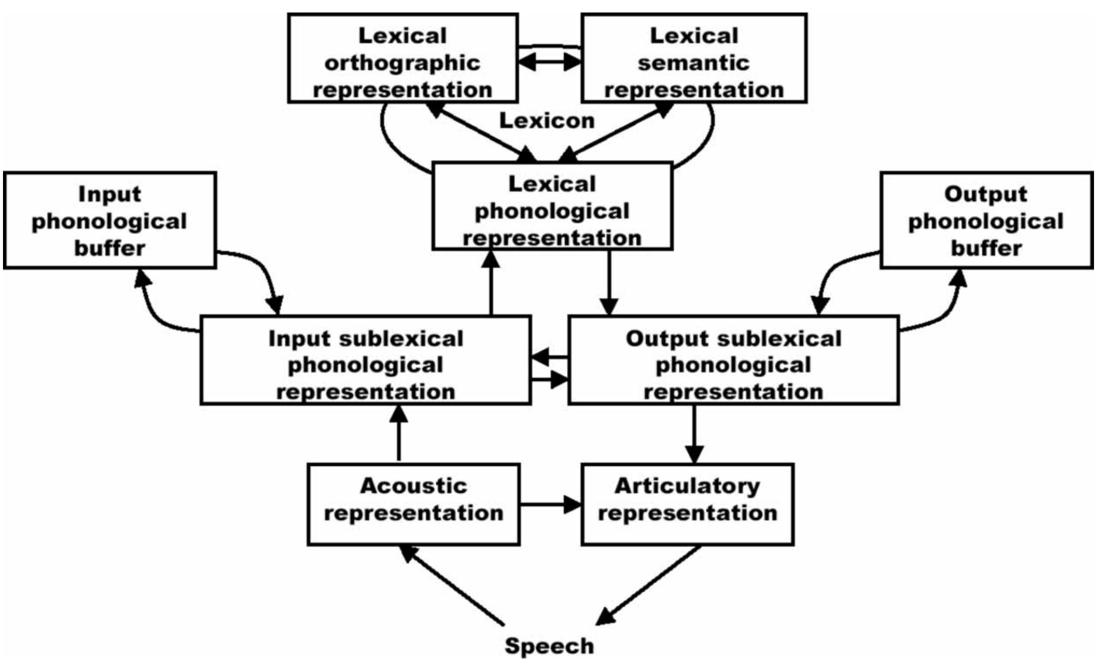

Figure 1. *An information-processing model of speech perception and production and lexical access.*

and we explain phonological and psycholinguistic concepts where they are necessary to understand our experiments.

More than 30 years of research on dyslexia have taught us that there are three main dimensions to the phonological deficit (Wagner & Torgesen, 1987):

- Poor phonological awareness (as exemplified in phoneme deletion tasks);
- Poor verbal short-term memory (as exemplified in digit span or nonword repetition tasks);
- Slow lexical retrieval (as exemplified in rapid automatic naming tasks).

The poor performance of persons with dyslexia in most (if not all) verbal tasks can be explained by one or several of these dimensions. A pertinent question therefore is why this "dyslexic triad" and why are the three dimensions affected together more often than to be expected by chance? The answer seems to be that the three dimensions have something in common: They all implicate phonological representations, each in its own way. The first dimension concerns conscious access, attention to, and manipulation of those representations and their subunits. Within Figure 1, this can be viewed as a central executive processor (not represented) accessing the contents of sublexical phonological representations. The second dimension refers to their storage for a short period of time, either briefly copied in phonological buffers (typically, holding the first words of a sentence for the very short time necessary to process the end), or actively recycling them between input and output sublexical representations (also known as the phonological loop, typically recruited in span tasks). Finally, the third member of the triad involves the retrieval of lexical phonological representations from long-term memory.

Therefore, it should come as no surprise that the most commonly accepted hypothesis regarding the nature of the phonological deficit in dyslexia is that phonological representations are degraded—that is, they are fuzzier, or noisier, or underspecified, or have a lower resolution or a larger grain size than they should, or are not sufficiently categorical and preserve too many acoustic or allophonic details (e.g., Adlard & Hazan, 1998; Elbro, 1998; Manis et al., 1997; Mody, Studdert-Kennedy, & Brady, 1997; Serniclaes, Van Heghe, Mousty, Carré, & Sprenger-Charolles, 2004; Snowling, 2000). Nevertheless, there is also much more to phonology than these three dimensions, and therefore the hypothesis of a deficit in phonological representations makes a host of additional predictions, concerning notably the early stages of phonological acquisition in the first few years of life and their consequences for on-line speech perception and production (Ramus, 2001b).

Exploring the phonological deficit

In the course of our investigations we have tested French university students with dyslexia. Self-reports of persons with dyslexia have been supplemented by data from a diagnostic battery, ensuring they met predefined inclusion criteria in terms of nonverbal IQ, reading disability, and presence of a significant phonological deficit (in the sense of the classic triad). Control students were also recruited and underwent the same tests, ensuring that they did not present any reading disability and that they were matched to the students with dyslexia in age and nonverbal IQ (Szenkovits & Ramus, 2005).

This population of university students was thought to be appropriate for testing with psycholinguistic tasks, which tend to be long, boring, and demanding. This does not excuse us from testing a more representative sample of children with age-appropriate tasks, but this was considered a second step after having delineated the most promising hypotheses to warrant confirmation in children.

In search of a locus

In a first series of experiments, we have attempted to assess specifically the most relevant levels of representations depicted in Figure 1 (Szenkovits & Ramus, 2005). Indeed, the general hypothesis of a phonological deficit does not by itself specify which of the different levels of phonological representation is presumed to be deficient.

In order to disentangle the various levels, we adopted the following strategy: We contrasted sublexical and lexical levels of representations by comparing tasks involving words and nonwords, and we contrasted input and output pathways by comparing repetition tasks (involving both) with auditory discrimination tasks (involving only input representations). To ensure that discrimination tasks were not performed by covert use of output representations (i.e., the phonological loop), we had an additional condition where the discrimination task was performed with concurrent articulatory suppression (uttering “bababa . . . ” for the whole duration of each trial, therefore keeping output representations busy). The material to be discriminated or repeated consisted of sequences of monosyllabic nonwords, of increasing length (i.e., nonword matching span). Verbal short-term memory load was an important aspect of all the experiments. In the discrimination task, two sequences were heard and compared, which either were identical or differed by one phonetic feature in one of the nonwords.

We found significant group differences in all conditions, suggesting that the phonological deficit appears no matter what levels are involved: sublexical as well as lexical, input as well as output, whether or not articulatory suppression was applied. Furthermore, participants with dyslexia were relatively more impaired in discrimination than in repetition tasks, highlighting more specifically their deficit in input representations. On the other hand, articulatory suppression slightly decreased overall performance, but did not impact differently on the two groups of participants. Thus, we are incited to take a closer look at the input pathway.

Representation versus working-memory processes

Why do persons with dyslexia fail to discriminate and repeat correctly verbal material, as soon as short-term memory load is significant? The previous series of experiments leaves open two broad classes of explanation that are not mutually exclusive. One is that phonological representations are degraded, so some phonetic features get lost in the process and are therefore missing when they must be compared or repeated. An alternative interpretation is that phonological representations are themselves intact—that is, that all phonetic features are correctly encoded—but that short-term memory processes are limited, and that the poor performance of participants with dyslexia reflect a capacity limitation.

We have attempted to test these contrasting hypotheses using the phonological similarity effect: The more phonologically similar the words or nonwords in the sequence, the more difficult it is to recall the sequence (Baddeley, 1984). This effect shows that verbal short-term memory is limited not only by general capacity constraints but also by possible phonological confusions between the items to be remembered. Now if the phonological representations of people with dyslexia are degraded, they should have even more confusions between items and therefore show an increased phonological similarity effect. On the other hand, if their phonological representations are intact, they should show just as much phonological similarity effect as controls, not more. Yet another conceivable prediction would be that they show less similarity effect than controls, although this is predicted only in the case of known words for which conceptual or visual representations are available (McNeil & Johnston, 2004; Shankweiler, Liberman, Mark, & Fowler, 1979).

We therefore carried out a new series of experiments requiring again the discrimination of sequences of nonwords, in two different conditions (Szenkovits, Dupoux, & Ramus, 2007b). In the minimal condition, sequences were made of repetitions of two to seven nonwords that differed by just one phonetic feature ([taz]–[taʒ]). The two sequences either were identical or differed by just one of the nonwords being changed into the other (i.e., they differed by one phonetic feature). In the maximal condition the two nonwords differed maximally ([taz]–[gum]), so that different sequences differed by three phonemes and quite a few phonetic features. Furthermore, in order to ensure that sequences were encoded at the phonological (rather than acoustic) level of representation, nonwords were uttered by two different voices, which alternated constantly within a sequence, and in opposite orders between sequences. As a result, even phonologically identical sequences were different at the acoustic level.

The main results were that we found a phonological similarity effect (poorer performance in the minimal than in the maximal condition) and that participants with dyslexia performed more poorly. However, as phonological similarity decreased the performance of the dyslexic group increased by the same magnitude as that for controls. This pattern of results held under various replication variants, with concurrent articulatory suppression, with sequence repetition rather than discrimination, and whether minimal and maximal conditions were intermixed or administered in separate blocks.

Our results extend previous studies that also found no differential phonological similarity effect, during verbal recall of words or letter names (Hall, Wilson, Humphreys, Tinzmann, & Bowyer, 1983; Johnston, Rugg, & Scott, 1987; Swanson & Ramalgia, 1992), as well as during paired-associate learning (Messbauer & de Jong, 2006). Overall, these results fail to confirm the predictions of the "degraded phonological representations" hypothesis. They are more compatible with the alternative hypothesis that the deficit might lie in the short-term memory processes operating on phonological representations (i.e., in Figure 1, the input and/or output phonological buffers, or the phonological loop between input and output sublexical representations).

Universal or hypernative phonology?

A great deal of phonology is specific to each particular language. This is best illustrated by the unique phonetic repertoire of each language, but is also true at other levels of the phonological hierarchy. It is generally agreed that adequate language-specific phonological representations are acquired very early on by the child, by the end of the first year of life by some accounts and at any rate before the end of the third. Given that the phonological deficit is presumed to be congenital, it should manifest itself early on in an altered pattern of phonological acquisition. The few longitudinal studies starting at birth that have directly tested that prediction (although very succinctly) have generally supported it (Guttorm, Leppänen, Richardson, & Lyytinen, 2001; Leppänen et al., 2002; Molfese, 2000; Richardson, Leppänen, Leiwo, & Lyytinen, 2003; van Alphen et al., 2004).

Beyond the first year of life, altered phonological acquisition predicts an "atypical" structure of phonological representations. Indeed, hypotheses emphasizing poor categorical perception and/or preserved allophonic perception rest on the idea that phonological categories were not properly acquired. These hypotheses more specifically assume that phonology was incompletely acquired, so that the phonology of the child (or adult) with dyslexia is closer to the initial, universal stage of phonology: Categories are less sharply defined and less specific to any particular language, and representations still incorporate some acoustic or allophonic details that should have been eliminated through phonological acquisition (e.g., Mody et al., 1997; Serniclaes et al., 2004).

One possible further prediction of this class of hypotheses is that, as a consequence, individuals with dyslexia might retain the ability to perceive and perhaps produce foreign speech sounds. This is because people's difficulties with foreign speech sounds are a direct outcome of their phonological acquisition, which rigidifies their phonology with the categories and processes of the native language, which are often in conflict with the categories and processes of a different, later acquired language. If the phonology of a person with dyslexia is less rigidified by their native language, it might retain some plasticity for a second one. As an example, French and English both have two categories for voicing, but with a different boundary. Korean has three categories. If say, an English speaker with dyslexia has less well defined English voicing categories, she or he might be less impaired in the perception of French voicing contrasts around a different boundary. They might be even less impaired in the perception of Korean voicing contrasts, if she or he has retained in his or her phonological representation the allophonic details that are the basis for the Korean contrast (as hypothesized by Serniclaes et al., 2004).

In order to tease apart the two hypotheses, we conducted a series of experiments testing the perception and production of foreign speech contrasts by people with dyslexia (Soroli, 2005). In order to assess the role of short-term memory load, we conducted discrimination and repetition tasks using either single consonant–vowel–consonant–vowel (CVCV) nonwords, or sequences of two or three CVCV nonwords. We tested one segmental and one suprasegmental phonological contrasts. The segmental contrast was the voicing of stop consonants in Korean, which, as mentioned above, presents three categories (plain/tense/aspirated) instead of two in French (the native language of all participants). The suprasegmental contrast was lexical stress, a prosodic contrast present in many languages like Spanish or Italian, but not in French. In that condition, stress could fall either on the first or the second syllable of the nonword, and different pairs differed only by the location of the stress, phonemes being kept identical. In the repetition tasks, participants' production was recorded and coded offline by a native speaker of Korean for segmental contrasts and a native speaker of Greek (a language with lexical stress) for stress contrasts.

Overall, the results showed that when discriminating or repeating single nonwords, participants with dyslexia showed the same performance as did controls. However, group differences appeared when discriminating or repeating sequences of two or three nonwords, particularly so for the stress contrast. These results suggest that the native phonological representations of people with dyslexia are equally (un)able to represent foreign speech contrasts. Group differences appear only when short-term memory load increases. These results therefore do not support the hypothesis of a universal (initial-stage) phonology. Again, they are more compatible with the hypothesis that the phonological representations of participants with dyslexia are intact and that short-term memory processes operating on them are impaired.

From the point of view of second-language acquisition, our results suggest that the difficulties of people with dyslexia in this domain may not result from the particular format of their phonological representations, but rather from their impaired verbal short-term memory and phonological awareness, and perhaps phonological learning, as these capacities must be heavily recruited during second language acquisition (Service, 1992).

Phonological grammar

Another area of phonology that is potentially of interest with respect to dyslexia is what can be termed "phonological grammar". This refers to a whole host of rule-like processes that apply (typically probabilistically) in speech production when phonological lexical items are retrieved from the lexicon and assembled (at the sublexical level) to make phrases (Chomsky & Halle, 1968). These phenomena are mainly described in speech production but similar phenomena occur in speech perception, either as a compensation for productive processes, or simply as an adaptation to native phonological structure. Most of these phonological processes are language specific and therefore must be learnt in the course of language acquisition. Do children with dyslexia acquire them equally well as controls?

Based on a series of experiments by Darcy et al. (Darcy, Peperkamp, & Dupoux, in press-a; Darcy, Ramus, Christophe, Kinzler, & Dupoux, in press-b), we tested one particular phonological process that occurs in French: voicing assimilation. In French, the voicing feature may spread backwards from obstruents or fricatives to the preceding consonant: for instance "cape grise" [ka**p**griz] → [ka**b**griz] (grey cloak). This assimilation process is both context specific (it does not occur before nasals: "cape noire" is always [kapnwar]; black cloak) and language specific (it does not occur in English, which instead shows assimilation of place of articulation: "brown bag" [brow**n**bag] → [brow**m**bag]).

In the production experiment, participants saw a sentence written on the computer screen, rehearsed it as much as needed, and then were recorded as they pronounced it rapidly. Sentences were read without difficulty by participants with dyslexia, the rehearsal ensuring that each sentence could be produced accurately and rapidly (to maximize the likelihood of producing assimilations), without being hindered by reading fluency. Sentences contained either a legal context for voicing assimilation (according to French phonology), or an illegal context for voicing assimilation (to assess context specificity). Other sentences contained similar conditions for English place assimilation (to assess language specificity). The words that could be assimilated were excised from the recordings of all participants and played, one at a time, to a new set of native French listeners, together with the written version of both the assimilated and unassimilated forms. These participants judged whether the target word was assimilated or not (i.e., in the above example, whether they heard [kap] or [kab]). This yielded the probability of producing an assimilation, for each target word, in each condition, by each subject. Results showed that French persons with dyslexia, just like controls, produce voicing assimilations around 40% of the time in legal contexts, but not in illegal contexts, and do not produce place assimilations. Furthermore, voicing assimilations occur more frequently than devoicing assimilations (Snoeren, Hallé, & Segui, 2006), to the same degree in the participants with dyslexia and controls.

In the perception experiment, similar sentences were played preceded by a target word (e.g., "ca**p**e"), the task being to detect whether the target word was included and correctly pronounced in the sentence. The sentences again came in three conditions. They either contained the target word in assimilated form in a legal context ("La petite fille jette sa ca**b** grise"; this should go unnoticed if participants compensate perceptually for voicing assimilation), or the target word in assimilated form in an illegal context ("la petite fille jette sa ca**b** noire"; this should be noticed because no assimilation is expected in this context), or did not contain the target word. Three additional conditions tested the possibility of compensation for place assimilation. Results showed that French participants with dyslexia compensate perceptually for voicing assimilations to the same extent as do controls (see also Blomert, Mitterer, & Paffen, 2004), but only in legal contexts (like controls), and do not compensate for place assimilation (like controls). Furthermore, an asymmetry in perceptual compensation was observed in perception as in production, to the same extent in people with dyslexia as in controls.

In another experiment, we investigated assimilations induced by phonotactic constraints. The background is that each language has its own phonotactic constraints, forbidding certain consonant clusters in certain contexts. In French, like in English, clusters like [dl] or [tl] can never occur at the beginning of a word. The consequence is that when French or English listeners hear a nonword such as [dla] or [tla], they most often assimilate it to the closest legal cluster ([gla] or [kla], respectively)—that is, they fail to hear the illegal cluster and report hearing the legal one (Hallé, Segui, Frauenfelder, & Meunier, 1998). This is also evident in discrimination tasks, where they for instance respond "same" to the "different" pair [dla]–[gla]. In such a discrimination task we found that listeners with dyslexia fall victim to this perceptual illusion just as much as controls, hearing [gla] instead of [dla]. Thus, their speech perception is constrained by the phonotactics of their native language as much as it is for controls.

In conclusion, the aspects of phonological grammar that we have investigated seem perfectly normal in people with dyslexia (Szenkovits, Darma, Darcy, & Ramus, 2007a). Our results are consistent with the hypothesis that phonological representations are intact, that grammatical processes that operate on them are intact too, and that the deficit lies somewhere else.

Unconscious speech processing and lexical access

A recurrent problem in psycholinguistics is that tasks typically require explicit instructions, attention to stimuli, and introspection, which may blur the interpretation of the effects observed, particularly so when the population tested has problems with phonological awareness. One solution to this problem is to observe indirect effects of experimental manipulations of which the subject is unaware. In the case of visual presentation of linguistic stimuli, subliminal priming has provided a particularly elegant solution. The participant performs a task (typically lexical decision) on a target word, which is preceded by a prime word. When presentation duration is sufficiently reduced, and when the prime is preceded and followed by visual masks, it is not consciously perceived, but may still be processed. One may therefore assess the effects of the prime on the recognition of the target, unbeknownst to the subject. More recently, a similar technique has been used to render auditory primes subliminal (Kouider & Dupoux, 2005). Kouider and Dupoux have used a combination of time compression, amplitude attenuation, and masking with backwards speech to achieve subliminal processing of the prime and have shown that subliminal repetition priming occurs, as evidenced by a decrease in reaction time compared to when the prime is unrelated to the target. Moreover, this priming is strictly lexical, and it operates on an abstract lexical phonological representation, because subliminal priming occurs only for words and resists large acoustic differences between prime and target (i.e., there is as much priming when prime and target are spoken by speakers of different sexes; Kouider & Dupoux, 2005).

The availability of this new method gave us the opportunity to consider new questions to ask about the phonological deficit in dyslexia—namely, how efficient are unconscious lexical access processes in people with dyslexia? What is the nature of their lexical phonological representations? The degraded phonological representations hypothesis predicts reduced subliminal repetition priming, due to the fact that phonological details might be lost and therefore distort the identity relationship between prime and target. A more specific hypothesis, according to which their phonological representations would be less abstract, and closer to acoustic representations, would predict decreased priming specifically across different speakers.

The findings from our study of control participants fully replicated those of Kouider and Dupoux (2005), and our results on dyslexia fully replicated those of controls (Gaillard, 2006). In short, participants with dyslexia show as much subliminal repetition priming as do controls, it is restricted to words like in controls, and it is of equal magnitude across as within speakers. These results do not support the predictions of the degraded phonological representations hypothesis, neither do they support the hypothesis that persons with dyslexia rely on acoustic rather than abstract phonological representations for their lexicon. Rather, they are compatible with the idea that their phonological representations and processes for lexical access are intact. Follow-up experiments manipulating the phonological relationship between prime and target will be needed to fully bolster the latter hypothesis.

A new hypothesis

The experiments that we have described were designed to test various hypotheses regarding the status of the phonological system in dyslexia. Overall, their findings converge towards one single conclusion: that the phonological representations of people with dyslexia are normal. Of course, this conclusion cannot be considered as proven. Many aspects of the phonological representations of people with dyslexia still remain to be tested. Nevertheless, let us consider for the sake of discussion that our conclusion holds. What, then, might be the nature of the phonological deficit? If phonological representations are normal, if phonological grammar is acquired normally, then what's wrong with phonology?

The first important remark to make is that our results do not challenge in any way the very existence of a phonological deficit. Indeed, our own data attest that our participants with dyslexia have a phonological deficit, as measured in the traditional sense, using for instance spoonerisms, nonword repetition, and rapid naming tasks. So it is not time to abandon the phonological deficit hypothesis, merely to rethink its precise formulation.

A comparison of phonological tasks in which participants with dyslexia show normal as opposed to poor performance provides important clues. First, task requirements, and in particular short-term memory load, seem paramount. This is obvious in span tasks where difficulties appear as sequence length increases. It is also the case in most phonological awareness tasks, which do require the subject to hold segmented phonological units in short-term memory, as well as requiring conscious access to those representations. In fact, the most difficult phonological awareness tasks for people with dyslexia turn out to be those that load most heavily on short-term memory (e.g., spoonerisms). One type of task that challenges persons with dyslexia without recruiting verbal short-term memory is rapid naming. Given that they do not always have problems with single picture naming, it seems that in this case the crucial task constraint is speed (Marshall, Tang, Rosen, Ramus, & van der Lely, 2007; McCrory, 2001; Szenkovits, Dupoux, & Ramus, 2007) (but see Snowling, van Wagtendonk, & Stafford, 1988; Swan & Goswami, 1997b).

In an attempt to provide a unifying explanation for those task constraints that seem to pose specific problems in dyslexia, we tentatively propose the concept of *phonological access*. By this, we mean all processes by which (lexical or sublexical) phonological representations are accessed for the purpose of external computations. Verbal short-term memory requires access to phonological representations for the purpose of copying them into buffers, then access to phonological buffers for retrieval (see Figure 1), as well as access to input representations to copy them into output representations, and access to output representations to recycle them into input representations (i.e., the phonological loop, Baddeley, 1984; Jacquemot & Scott, 2006). Phonological awareness tasks additionally involve a special type of access, *conscious access* to phonological representations, which may place special demands on access mechanisms. And rapid naming tasks require multiple fast access to lexical phonological representations. Therefore, it seems to us that people with dyslexia tend to fail at tasks that are particularly demanding in terms of phonological access. A relatively similar proposal was made by Shankweiler and Crain (1986) under the name of *processing limitation hypothesis*. There are also some commonalities with Hulme and Snowling's (1992) notion of an *output deficit*.

We acknowledge that, at the present stage, our notion of phonological access needs developing and that our analysis of which tasks are demanding in terms of access is rather ad hoc. Ultimately, computational models of the phonological system would be the best way to provide an operational definition of access and to make unambiguous predictions concerning the consequences of a phonological access deficit on the performance of various tasks.

Discussion

The most striking aspect of the series of experiments that we have reported here is our consistent failure to demonstrate a deficit in the phonological representations of people with dyslexia. Could obvious reasons explain our failure? Could it be that our unrepresentative, well-compensated participants with dyslexia were not dyslexic enough, or did not present a phonological deficit at all? It should be recalled that all our participants were included on the basis of both a history of reading disability and poor performance on reading and standard phonological tasks. In fact their performance on standard phonological tasks (spoonerisms, digit span, rapid naming) did not overlap at all with that of age- and IQ- matched participants. Therefore there is good evidence that our participants with dyslexia did present a phonological deficit. But this deficit surfaces in some tasks and not in others, and the whole point of our hypothesis is to explain why.

Another potential limitation of our findings is that, in working with adults, we cannot rule out the possibility that people with dyslexia may have deficient phonological representations as children, but these representations have recovered when we test them in adulthood (e.g., Goswami, 2003). Obviously this type of critique must be taken seriously, and the only way to do so will be to replicate our main findings on children. Nevertheless, this type of hypothesis does not easily explain why performance on tasks tapping fine aspects of the phonological representation would recover, while performance on the same tasks with additional short-term memory load, or conscious awareness, or time constraints, would not. Clearly, the developmental critique is plausible to the extent that it is able to adequately explain what recovers and what does not.

Our present findings, and our conclusion that the phonological representations of people with dyslexia are normal, may seem quite provocative, but after all, are they surprising at all? In hindsight, one may consider that similar data have been around for a long time. For instance, we have always known that most children with dyslexia can repeat one- and two-syllable nonwords without much problem, and that difficulties appear only with three-, four-, and five-syllable nonwords. Such data do suggest that phonological representations are normal, and that only memory load makes a difference. In a landmark study, Swan and Goswami (1997a) tested phonological awareness in children with dyslexia while controlling for their ability to correctly retrieve the phonological form of the target words. While their findings are widely interpreted as supporting a form of the degraded phonological representations hypothesis, they have in fact shown that the phoneme awareness deficits of children with dyslexia cannot be entirely attributed to poor phonological representation of the target words. In another line of research, studies that have directly tested the quality of phonological representations in dyslexia with categorical perception experiments have often had mixed results: They sometimes found significant group differences, but often due to a subgroup of participants with dyslexia (e.g., Adlard & Hazan, 1998; Mody et al., 1997; Ramus et al., 2003b; Rosen & Manganari, 2001; White et al., 2006b). This suggests that deficits in the categories of phonological representations, just like basic auditory perception deficits, affect only a minority of persons with dyslexia and may not be part of the core phonological deficit in dyslexia.

Does our phonological access hypothesis imply a more general executive dysfunction in dyslexia? Certainly access to representations for the purpose of working memory or awareness is part of what could be termed executive function. Nevertheless, we are not proposing a general executive dysfunction in dyslexia in the same sense as executive dysfunction in autism or in frontal patients. This must be a very specific type of executive dysfunction, specific both in terms of executive processes and in terms of modality (e.g., Jeffries & Everatt, 2004). Executive function is a domain-general concept, but in practice it is plausible that the neural substrate of executive processes has central (frontal) components (which are not affected in dyslexia) and is partly distributed in each sensory modality and functional module (Carpenter, Just, & Reichle, 2000). Then it is possible to envision that, say, a left perisylvian dysfunction might disrupt executive processes only as applied to verbal (or auditory) material.

The matter of sensory deficits in dyslexia is also of interest here. Indeed, after years of investigations of auditory and visual deficits in dyslexia, some researchers have come to conclusions that are intriguingly similar to ours. Ahissar and colleagues have found that the difficulties of people with dyslexia never seem to be specific to a particular kind of stimulus, be it auditory or visual: Rather they appear or disappear depending on task requirements, being particularly prominent when the stimuli must be stored in short-term memory (Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Banai & Ahissar, 2006; Ben-Yehudah, Sackett, Malchi-Ginzberg, & Ahissar, 2001). In their interpretation, the deficit lies in the ability to "form a perceptual anchor" (Ahissar, Lubin, Putter-Katz, & Banai, 2006). Similarly, working on visual processing, Sperling and colleagues concluded that the deficit in dyslexia does not lie specifically with stimuli tapping the magnocellular system, but rather lies in the ability to perform the task when the stimuli are noisy: in their own words, a deficit in "perceptual noise exclusion" (Sperling, Lu, Manis, & Seidenberg, 2005, 2006). This is not without recalling the finding that children's difficulties with speech perception are exacerbated by presentation in noise (Brady, Shankweiler, & Mann, 1983; Cornelissen, Hansen, Bradley, & Stein, 1996; but see Snowling, Goulandris, Bowlby, & Howell, 1986) or under conditions where the stimuli are extremely minimal (Serniclaes et al., 2004). Rephrased within our framework, the interpretation of these results is that the auditory and visual representations of people with dyslexia are intact, but that they have difficulties accessing them under certain conditions involving storage in short-term memory, speeded or repeated retrievals, extraction from noise, and other task difficulty factors. Does this imply that individuals with dyslexia in fact suffer from a *general deficit* in the capacity to access sensory representations? The critique of sensory theories of dyslexia retains its force (Ramus, 2003); simply, for those who, on top of their phonological deficit, do show auditory and/or visual deficits, these may be construed in terms of access to representations, just like the phonological deficit. Therefore, individuals with dyslexia may have cognitive deficits of a single type, but expressed in several domains, with most of them having a deficit in the phonological domain (hence the link with reading disability), and some having the same kind of deficit more generally in the auditory and/or visual domains (and possibly elsewhere). The range of deficits within a particular individual would presumably depend on the spatial extent of their cortical dysfunctions (Ramus, 2004).

To summarize, a whole series of experiments conducted in our lab suggests that the phonological representations of people with dyslexia are basically intact, and that the phonological deficit surfaces only as a function of certain task requirements, notably short-term memory, conscious awareness, and time constraints. In an attempt to reformulate those task requirements more economically, we propose that they have a deficit in access to phonological representations. The same type of deficient access to representations may turn out to adequately characterize the additional sensory and cognitive deficits of the subset of individuals who have them.

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