Developmental dyslexia: The difficulties of interpreting poor performance, and the importance of normal performance

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This paper provides a selective review of data on phonology, audition, vision, and learning abilities in developmental dyslexia, with a specific focus on patterns of normal alongside poor performance. Indeed we highlight the difficulties of interpreting poor performance, and we criticize theories of dyslexia that are exclusively suited to explaining poor performance, at the risk of overgeneralizing and predicting deficits in many more situations than are observed. We highlight a number of tasks and conditions where individuals with dyslexia seem to show perfectly normal performance, and we discuss the value of taking such data seriously into account and the difficulties of current theories to explain them. Finally, we discuss the experimental challenges for tasks investigating the nature of cognitive deficits in dyslexia and in other developmental disorders and the challenges for any proper theory of dyslexia aiming to explain cases of normal as well as poor performance.

Keywords: Cognitive development; Developmental dyslexia; Phonology; Anchoring; Sensory processing.

Developmental dyslexia is a common learning disorder affecting about 3–7% of the population (Lindgren, De Renzi, & Richman, 1985). It is defined as a specific deficit in reading acquisition that cannot be accounted for by low IQ, poor educational opportunities, or an obvious sensory or neurological damage (World Health Organization, 2008). It is quite remarkable that such a seemingly simple and circumscribed disorder has engendered a truly unique profusion of theories.

The first descriptions of developmental dyslexia viewed it as a "congenital word blindness" (Hinshelwood, 1900; Morgan, 1896; Stephenson, 1907), and indeed visual symptoms and hypotheses have dominated the best part of the 20th century (Dunlop, 1972; Hallgren, 1950; Orton, 1937). It is only in the 1970s, with the development of research on speech perception, in particular at Haskins Laboratories, that apparent visual confusions were reinterpreted as phonological ones,

and that the theory of a phonological deficit emerged and gradually became predominant (Brady & Shankweiler, 1991; Liberman, 1973; Shankweiler & Liberman, 1972; Shankweiler, Liberman, Mark, & Fowler, 1979).

Around the year 2000, the theoretical landscape of dyslexia was a battleground between the hypothesis of a specific phonological deficit (Snowling, 2000; Vellutino, 1979), and alternative theories invoking either rapid temporal processing (Tallal, Miller, & Fitch, 1993), magnocellular function (Stein & Walsh, 1997), or the cerebellum (Nicolson & Fawcett, 1990; Nicolson, Fawcett, & Dean, 2001). These alternative theories have in return faced strong criticism (e.g., Amitay, Ahissar, & Nelken, 2002; Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Banai & Ahissar, 2006; Ben-Yehudah, Banai, & Ahissar, 2004; Ben-Yehudah, Sackett, Malchi-Ginzberg, & Ahissar, 2001; Ramus, 2001a, 2003, 2004; Ramus et al., 2003; Skottun, 2000; White, Frith, et al., 2006; White, Milne, et al., 2006).

However, far from establishing the supremacy of the specific phonological deficit theory, the unexpected consequence of this criticism has been the appearance of a profusion of new theoretical proposals, as diverse as sluggish attentional shifting (Hari & Renvall, 2001), a noise exclusion deficit (Sperling, Lu, Manis, & Seidenberg, 2005), a perceptual-centre perception deficit (Goswami, 2003), an anchoring deficit (M. Ahissar, 2007), procedural learning difficulties (Nicolson & Fawcett, 2007), a phonological access deficit (Ramus & Szenkovits, 2008), a visual attention deficit (Bosse, Tainturier, & Valdois, 2007; Vidyasagar & Pammer, 2010), and abnormal temporal sampling (Goswami, 2011). The abundance and diversity of these new theories partly stem from the fact that the large body of data on cognitive deficits in dyslexia fails to fit into a single coherent theoretical framework. It also partly reflects the limits of our current understanding of human cognition. Thus the relations between temporal auditory processing (or sampling) and the development of phonological representations are not well understood, and the notions of perceptual noise exclusion, anchoring, and access

need to be more precisely defined and integrated into broader models of perception, attention, working, and long-term memory.

Additional factors of complexity include the fact that the disorder is heterogeneous, to the extent that several subtypes of dyslexia have been considered (Bakker, 1992; Boder, 1973; Bosse et al., 2007; Castles & Coltheart, 1993). Thus different theories might be correct for different subtypes. At the moment, the available data on deficits most proximal to reading are roughly consistent with the existence of a majority subtype characterized by a phonological deficit and one or several minority subtypes characterized by a visual deficit (Bosse et al., 2007). Additional subtypes of phonological and visual dyslexia might emerge from the consideration of underlying aetiologies. For instance, a certain proportion of dyslexic individuals have been shown to have broader deficits in the auditory domain: They might constitute a specific subtype of phonological dyslexia. Similarly, several hypotheses of visual dyslexia have been proposed, such as magnocellular dysfunction or reduced visual attention span: They might constitute distinct subtypes of visual dyslexia. However, apart from a few exceptions, most published studies rely on unselected groups of dyslexic participants. They typically report clear evidence that a majority of these cases have a phonological deficit. Thus their results must be skewed towards the cognitive profiles typical of the main phonological subtype. Yet these results show large inconsistencies between studies and remain compatible with multiple theories. We are not aware of any study successfully defining subtypes of dyslexia and providing evidence for distinct, reliable, cognitive (or biological) profiles associated with each subtype, although the study by Bosse et al. (2007) may be the best candidate so far.

It seems that the reason why so many different theories of dyslexia have been proposed is that deficits have been found in an astonishing variety of tasks. The dyslexia literature looks as if almost any new task investigated in dyslexic and control individuals were likely to show significantly poorer performance in the dyslexic group.

Sometimes, questions are raised as to what extent such poor performance may be due to below-average intellectual abilities (e.g., Amitay, Ahissar, et al., 2002; Hulslander et al., 2004). In the best controlled cases, however, poor performance occurs in a context of generally preserved or matched (at least nonverbal) intellectual ability. Ideally, normal performance is demonstrated on a control task measuring similar abilities under a condition that differs by a crucial parameter. Indeed, conditions under which performance is normal are crucial for the interpretation of conditions that yield poor performance, otherwise developmental dyslexia might be easily confounded with a minor intellectual disability or a generalized form of learning disability.

In the present paper, we argue that the greatest stumbling block for any theory of dyslexia is to explain both cases where dyslexic individuals perform poorly and cases where they perform normally. All too often, both phonological and domain-general theories of dyslexia are designed to fit patterns of poor performance exclusively, overlooking normal performance. In so doing, they run the risk of overgeneralizing—that is, of predicting poor performance in many more situations than are observed. Our argument is illustrated by a selective review of patterns of good and poor performance in dyslexia, which are still in need of a coherent explanation.

Patterns of normal and abnormal performance in developmental dyslexia

Phonology

Phonology refers to the mental representation and processing of speech sounds, both in perception and in production. Poor performance of dyslexic individuals has been consistently demonstrated in three broad areas involving phonology: phonological awareness (explicitly attending to, judging, and manipulating speech sounds), verbal short-term and working memory (short-term storage, manipulation, and repetition of words or pseudo-words), and rapid automatized naming (RAN: speeded retrieval and naming of lists of digits, colours, or objects; Wagner & Torgesen, 1987).

Whether these three components are independent or reflect a common underlying deficit remains an open question. The general consensus is that dyslexic individuals' phonological representations are degraded (a hypothesis that has been formulated in a number of different versions, e.g., noisy, sparsely coded, underspecified, with poor spectral or temporal resolution ...), and that this explains at least the first two components, and perhaps slowed rapid naming as well, at least to some extent.

As previously discussed by Ramus and Szenkovits (2008), tasks that involve phonology and that yield reliably poor performance of dyslexic individuals tend to require either explicit and complex mental manipulations of speech sounds or a high short-term or working memory load, or speeded conditions, or additional factors that make the task particularly difficult. There is no doubt that the hypothesis of degraded phonological representations, no matter the form that it takes, does predict poor performance in all these tasks. Our concern here is that it also predicts poor performance in a much broader range of tasks (see Ramus, 2001b) in which dyslexic individuals show far less obvious difficulties. We thus now focus on evidence for normal phonological performance in dyslexia.

Given that the primary function of phonology is to speak, using specific native-language phonemes and phonological processes, the most obvious prediction of the degraded phonological representations hypothesis should be that dyslexic individuals speak differently. However, there is very little evidence for that. There is broad agreement that dyslexic individuals speak perfectly normally. Informal clinical observations sometimes suggest a greater prevalence of word-finding difficulties and of slips of the tongue, but we are not aware that this has been confirmed experimentally (see C. R. Marshall, Harcourt-Brown, Ramus, & van der Lely, 2009, for evidence of normal word-finding abilities). Using word production tasks measuring the accuracy and distinctness of the pronunciation of target words, Elbro, Borstrom, and Petersen (1998) did provide data consistent with the idea that

dyslexic children's lexical phonological representations might be underspecified. Furthermore, Lalain, Joly-Pottuz, and Habib (2003) have provided evidence for subtle deviations of certain aerodynamic parameters in dyslexic children's articulation of certain stop consonants. Fowler and Swainson (2004) replicated the observations of Elbro and colleagues, although it should be said that group differences were small and emerged in only some of the measures investigated. It remains unclear to what extent these results may be due to some individuals demonstrating a comorbidity between dyslexia and speech delay, speech sound disorder, or specific language impairment.

The degraded phonological representations hypothesis should also predict that lexical phonological retrieval should be slower and/or more prone to errors. However, while results from serial naming under speeded conditions (in RAN) clearly show slower performance, results from single picture naming typically do not (Elbro et al., 1998; McCrory, 2001). This therefore suggests that dyslexics' difficulties with RAN are due to the sequential aspects of the task, more than to the stage of phonological retrieval.

On the perception side, the degraded phonological representations hypothesis should predict widespread disruption of the categorical perception of phonemes. There has been a lot of research in this area, but the results are far from overwhelming. A number of studies have found significantly shallower curves for the categorical perception function of certain consonant contrasts, but these results seemed to hold only in a minority of dyslexic children (Adlard & Hazan, 1998; Breier et al., 2001; Manis et al., 1997; G. McArthur, Atkinson, & Ellis, 2009; Mody, Studdert-Kennedy, & Brady, 1997; Paul, Bott, Heim, Wienbruch, & Elbert, 2006; Rosen & Manganari, 2001) or only under specific conditions (e.g., with synthetic but not with natural speech; Blomert & Mitterer, 2004). Other studies failed to find significant group differences (Hazan, Messaoud-Galusi, Rosen, Nouwens, & Shakespeare, 2009; Ramus et al., 2003; Robertson, Joanisse, Desroches, & Ng, 2009; White, Milne et al., 2006).

Even under noise, which is assumed to magnify any subtle speech perception deficit, the evidence for a deficit is quite mixed (Brady, Shankweiler, & Mann, 1983; Chandrasekaran, Hornickel, Skoe, Nicol, & Kraus, 2009; Cornelissen, Hansen, Bradley, & Stein, 1996; Hazan et al., 2009; Inoue, Higashibara, Okazaki, & Maekawa, 2011; Robertson et al., 2009; Snowling, Goulandris, Bowlby, & Howell, 1986; Ziegler, Pech-Georgel, George, & Lorenzi, 2009). A comparison of studies that do and do not find group differences in speech perception in noise may suggest that differences are found only at very low signal/noise ratios (e.g., Ziegler et al., 2009) or under additional constraints (e.g., under high but not low presentation rate; Inoue et al., 2011).

Interestingly, lexical decision tasks sometimes reveal subtle differences between dyslexics and controls (Janse, de Bree, & Brouwer, 2010), although not compared to a reading-age control group (Poulsen, 2011). It remains an open question to what extent these small effects might be due to the metalinguistic demands of the lexical decision task ("is this a word or a nonword?"). Thus, for example, a cognitively less demanding lexical recognition task such as picture–word matching ("pear" or "bear"?) shows no group differences, even with chronological-age control children, whether in silence or in noise (C. R. Marshall, Ramus, & van der Lely, 2010).

The relative sparing of both input and output phonological processing is further confirmed in tasks involving both at the same time—for example, pseudoword repetition and various span tasks. Indeed, whereas a deficit in verbal short-term memory is well documented in dyslexia, it surfaces only when longer pseudowords or sequences are used. But the positive (and often overlooked) side of these results is that dyslexic individuals typically have no difficulty repeating 1- to 3-syllable pseudowords, thus showing no deficit in the accuracy of their perception and production (e.g., C. R. Marshall & van der Lely, 2009; Szenkovits & Ramus, 2005), which would not be expected if they misrepresented some aspects of phonological representations.

Another area that has received a lot of attention recently is prosody. Although there have been suggestions that the perception of certain acoustic cues to prosody may be impaired in dyslexia (Goswami et al., 2002; Goswami et al., 2011), these results do not seem to translate to speech prosody in a simple manner. In one study using a prosodic skills battery (Peppé & McCann, 2003), it has been found that children with dyslexia showed normal prosodic perception and production skills, and that their ability to use prosody for linguistic purposes (semantic or syntactic disambiguation) was at the level predicted by their linguistic abilities (C. R. Marshall et al., 2009). Another study did find that dyslexic children had difficulties with prosodic perception, but using a version of the DeeDee task, which involves making explicit judgements about prosody (Goswami, Gerson, & Astruc, 2010). This was confirmed in a similar study on dyslexic adults using a different, but still explicit, stress perception task (Leong, Hamalainen, Soltesz, & Goswami, 2011). Another study conducted on adult participants provided a partial replication, finding a striking dissociation between deficits in the awareness of prosodic patterns (using a version of the DeeDee task) and spared automatic processing of prosody, as measured by a task that did not explicitly bear on prosodic patterns, but that used speech material whose prosody was either congruent or incongruent (Mundy, 2011; Mundy & Carroll, in press). Finally, another study on adults reported difficulties in perceiving and producing foreign stress patterns, but that seemed to be entirely explained by the metaphonological nature of the task and by short-term memory load (Soroli, Szenkovits, & Ramus, 2010). Thus, it seems that deficits in prosody perception or production are found in individuals with dyslexia only to the extent that the tasks used involve metalinguistic judgements or other difficulty factors.

Another area where deficits might be expected in dyslexia is phonological grammar. These are regular, language- and context-dependent variations introduced by speakers in their fluent speech, which are taken into account by listeners for correct lexical recognition. If certain phonetic features (such as voicing or place of articulation) were less well represented by dyslexic individuals, they should produce less distinct phonological variations (such as assimilations, liaisons), in a manner that is less consistently dependent on phonological context. However, the few studies that have investigated the issue have consistently found normal perceptual compensation for assimilation processes in dyslexia (Blomert, Mitterer, & Paffen, 2004; C. R. Marshall et al., 2010; Szenkovits, Darma, Darcy, & Ramus, 2012). Another study investigating the sensitivity to well- and ill-formed consonant sequences in Hebrew reached the same conclusion (Berent, Vaknin, & Marcus, 2007; Berent, Vaknin-Nusbaum, Balaban, & Galaburda, 2012).

To mention one last area that has been recently investigated, Soroli and colleagues (2010) reported no evidence that dyslexic individuals might have more (or less) difficulty perceiving and producing foreign speech sounds than controls, again contrary to predictions made by the standard phonological deficit hypothesis.

Thus there is widespread evidence for normal performance of dyslexic individuals in many aspects of phonology, in tasks and conditions where most theories of the phonological deficit predict poor performance. The hypothesis of a deficit in the access to phonological representations was proposed to fill this gap (Ramus & Szenkovits, 2008); however, at this stage it is quite sketchy and underspecified. It remains a considerable challenge for theories of dyslexia to explain the specific pattern of poor and normal performance that is observed in the phonological domain.

Auditory processing

In a classic series of studies, Tallal and collaborators targeted the notion of "rapid" or "temporal" auditory processing in dyslexia and specific language impairment. For this purpose, they used the temporal order judgement task and its variants, and they manipulated the time interval between the two sounds whose order was to be judged. They reported poor performance of

dyslexic children at short but not at long intervals (Tallal, 1980). This is precisely the sort of contrast between poor and normal performance that we are advocating here, and indeed this contrast played a crucial role in the broad influence of the temporal auditory processing theory. As is now well known, this theory has been criticized on the grounds that processing deficits for short intervals had a relatively low prevalence in dyslexia (e.g., Ramus, 2003; White, Milne, et al., 2006). What may be less well known is that the theory was also criticized on the side of normal performance at long intervals. Indeed, as pointed out by Rosen (2003), group differences vanished at long intervals because both groups reached ceiling performance. However, studies designed to avoid ceiling effects found group differences of the same magnitude at long and at short intervals (C. M. Marshall, Snowling, & Bailey, 2001; Nittrouer, 1999; Reed, 1989; Share, Jorm, MacLean, & Matthews, 2002; Waber et al., 2001). Other types of paradigms, such as frequency- or amplitude-modulation detection, did not find much evidence of a specificity of deficits at high temporal frequencies (Goswami et al., 2002; Lorenzi, Dumont, & Füllgrabe, 2000; Witton, Stein, Stoodley, Rosner, & Talcott, 2002; Witton et al., 1998). In a nutshell, manipulating the temporal dimension in auditory processing has produced inconsistent findings and has not yielded the clear pattern of poor and normal performance that was initially suggested.

M. Ahissar, Protopapas, Reid, and Merzenich (2000) largely replicated Tallal's (1980) findings in adult dyslexics. However, the same participants tended to also show difficulties in a series of other auditory discrimination tasks, such as frequency and duration discrimination. Moreover, the degree of difficulties was correlated across tasks. Namely, these were largely the same individuals who had the greatest difficulties across different dimensions (M. Ahissar et al., 2000; Banai & Ahissar, 2004). Furthermore, the individuals with the largest auditory difficulties also had broader verbal working memory deficits. Overall, these studies found no evidence for a *specific* deficit in the ability to identify rapidly varying

stimuli. Thus, for example, the minimal duration needed for the detection of a gap in a continuous noise was not longer among dyslexics than among controls (M. Ahissar et al., 2000). Additionally, dyslexics did not show a deficit when brief stimuli were presented, and the frequency difference was "custom tailored" so that it was perceptually (rather than physically) equated across participants (Amitay, Ahissar, et al., 2002).

The observation that auditory deficits are largely correlated across tasks and dimensions links with other theories suggesting a contrast in the temporal domain, in a different temporal range. Indeed, it has been suggested that processing of larger temporal scales, important for speech segmentation at the syllabic level (Goswami et al., 2002) and for tracking the envelope of sentence amplitude modulation (4–16 Hz; E. Ahissar et al., 2001; Goswami, 2011; Goswami, Wang, et al., 2010; Hamalainen, Fosker, Szucs, & Goswami, 2011), is specifically impaired in dyslexia. Yet, when individuals' performance was measured in a variety of tasks tapping this relatively slow temporal processing as well as frequency discrimination, both were impaired to a similar extent (Huss, Verney, Fosker, Mead, & Goswami, 2011). It is difficult to explain why poor processing in this temporal range should lead to poor frequency discrimination. However, the implication of this lower frequency range potentially shifts the focus of the contrast from the perceptual to the attentional scale. Indeed, lower frequencies ($\sim$2 Hz) may characterize attentional processes required for perceptual integration and explicit object identification.

While the ability to identify stimuli that include rapid changes does not seem specifically impaired, many studies found difficulties in the ability to rapidly *identify* brief, serially presented stimuli. In other words, the temporal processing bottleneck, rather than being at a low level (ability to implicitly process fast modulations), seems to be situated at a higher level, where the limiting factor is the rate of explicit identification, perhaps due to a slowness of incorporation into explicit processes. The time scale that is relevant for the former is around 30 Hz—for example,

the rate of transients that differ between /ba/ and /da/, whereas the time scale for the latter is around 3 Hz. The latter is relevant for fast serial object identification—for example, for identifying /ba/−/da/ as opposed to /da/−/ba/. Thus, Tallal's (1980) two-tone repetitions may in fact tap the latter time scale rather than the former, though the original interpretation was just the opposite. This interpretation is consistent with the finding that deficits in slow temporal processing are linked with poor performance in tasks requiring explicit judgements on the prosody of serially presented words or syllables (Goswami, Gerson, et al., 2010; Leong et al., 2011). In fact, many studies replicated difficulties in fast serial identification, of visual (e.g., Hari & Renvall, 2001) and auditory (e.g., Ben-Yehudah et al., 2004) stimuli. Many dyslexic participants need longer interstimulus intervals for reliable identification. This interpretation may also be in line with magnetoencephalography (MEG) data showing tracking difficulties around this temporal range. According to our revised interpretation, poor tracking is the outcome of slow identification, rather than revealing more basic segmentation processes (E. Ahissar et al., 2001). Our interpretation is also consistent with evidence of poor performance in auditory short-term memory tasks (Laasonen et al., in press).

In summary, on the one hand, there is substantial evidence for poor performance in a range of auditory tasks in dyslexia. On the other hand, attempts to delineate a simple contrast along a well-defined dimension—for example, along a particular frequency range (whether high or low)—fail to account for the whole body of data. A consistently repeated pattern is a difficulty in fast serial identification, which may not be specific to auditory stimuli. This description is compatible with both Tallal's (1980) classical findings and with Goswami's (2011) more recent investigations. However, we have offered a somewhat different interpretation of these results from that of either author.

Moreover, the nature of auditory difficulties may vary across subpopulations of dyslexics. Individuals with a broader profile of linguistic deficits tend to have a broader profile of auditory deficits (e.g., Heath, Hogben, & Clark, 1999; G. M. McArthur & Hogben, 2001), which is often concurrent with somewhat broader cognitive deficits. Our suggestion of a relatively selective deficit in fast serial identification may be more characteristic of individuals who are high academic achievers and tend to be overall slow yet accurate, both in their auditory identification and in their pattern of reading difficulties (Amitay, Ahissar, et al., 2002; Ben-Yehudah et al., 2004). Individuals with broader academic deficits may also have broader perceptual deficits.

Visual processing

As we have recalled in the introduction, dyslexia has long been believed to be a predominantly visual disorder. In the 1980s and 1990s, there were several attempts to explore the aetiology of dyslexia in visual pathways. Thus, Livingstone and colleagues (Livingstone, Rosen, Drislane, & Galaburda, 1991) suggested a specific impairment in the subsystem that processes faster changes in the visual modality, the magnocellular system. The conceptual link was the role that was attributed to the magnocellular system as inhibiting the parvocellular system during saccades and thus eliminating potential blur due to continuous activation of the sustained parvocellular system (e.g., Stein & Walsh, 1997). However, at about the same time it was found that the parvocellular system is not suppressed during saccades. Rather, the magnocellular system is (Burr, Morrone, & Ross, 1994). Yet, the elegant idea of a magnocellular dysfunction, which makes clear behavioural predictions, has inspired the majority of visual studies in the past 30 years.

Based on the few monkey studies that assessed the outcomes of lesions in the magnocellular layers of the lateral geniculate nucleus of the thalamus (Merigan, Byrne, & Maunsell, 1991; Schiller, Logothetis, & Charles, 1990), studies assessing the magnocellular hypothesis focused on contrast sensitivity to moving or flickering grating stimuli and on a variety of motion discrimination tasks (for a review, see Skottun, 2000). Most studies did not compare sensitivity within the

magnocellular range with sensitivity in the non-magnocellular (i.e., parvocellular) range. When these were contrasted, for example, by comparing the impact of temporal frequency, or by comparing the consistency of the deficit across different magnocellular tasks, neither consistent nor specific magnocellular deficits were found (e.g., Amitay, Ben-Yehudah, et al., 2002).

The failure to find a specific magnocellular deficit led to two types of modification to the original hypothesis. One suggested that the deficit relates only to temporal aspects within the magnocellular range (McLean, Stuart, Coltheart, & Castles, 2011) and may affect both dorsal and ventral pathways that receive fast conducting neuronal fibres. Based on this conceptualization, several studies assessed the maximal temporal frequency at which participants still detect flicker (and do not experience a perceptual fusion), with isoluminant red–green flickers, which cannot be detected by the "colour-blind" magnocellular system, versus a flicker with an intensity contrast, which can be detected by the magnocellular system. This modified magnocellular hypothesis predicts a specific deficit in the latter condition. A marginal contrast was found in the expected direction. Yet performance thresholds were mainly correlated with generally slower response times, whose relations either with magnocellular performance (Skottun & Skoyles, 2007) or with specific reading skills are not clear.

Another rephrasing of the magnocellular hypothesis focuses on higher processing stages (spatial attention skills) of the dorsal stream, which receives most of its inputs from the magnocellular system (Stein & Walsh, 1997; Vidyasagar & Pammer, 2010). It suggests that the dorsal stream serially selects the positions of letters or letter sequences whose identity is subsequently determined by the ventral stream (Vidyasagar & Pammer, 2010). Furthermore, the idea is that mechanisms of serial search (on which visual reading procedures rely) are impaired in dyslexia, whereas parallel search for simple salient features, which does not require serial attention, is unimpaired. Yet, the claim for a contrast between unimpaired parallel search and impaired serial search

has been challenged by other studies (e.g., Moores, Cassim, & Talcott, 2011) that reported other types of difficulties in the spatial allocation of attention—for example, an increased crowding effect (interference caused by a high density of similar neighbouring elements), as was already suggested years ago (Geiger & Lettvin, 1987). However, if dyslexics do have increased crowding effects, these seem to relate to their peripheral and not their foveal vision (Shovman & Ahissar, 2006), and thus their relevance to reading is not well understood.

The view of impaired serial attention was also promoted by Hari and colleagues, who suggested that dyslexics' attention is "sluggish"—namely, that it works somewhat more slowly and is perhaps less spatially refined (Hari & Renvall, 2001). This concept was supported by additional studies showing impaired serial visual identification (Ruffino et al., 2010) and a slower spatial cuing (Facoetti et al., 2010), particularly among dyslexic children with phonological difficulties. Although "sluggish" attention is a fuzzy description, it does make certain predictions. First, serial rather than parallel identification will be relatively more challenging for dyslexics. Second, the relevant time scale for dyslexics' difficulties is ~1–4 Hz (rather than faster time scales), and perhaps similar deficits will be found across modalities (see Facoetti et al., 2010). These predictions are consistent with our interpretation of the auditory findings described above. Moreover, they are consistent with visual studies that were aimed to assess serial versus parallel processing deficits, both in contrast detection (Ben-Yehudah et al., 2001) and in spatial discrimination tasks (spatial frequency discrimination between gratings; Ben-Yehudah & Ahissar, 2004; Ben-Yehudah et al., 2001). The interpretation of slower serial identification is also consistent with results of increased search time under challenging conditions, since these conditions require serial identifications and perhaps also serial comparisons with a template of the searched target (Sung, 2008). Which of the required stages for serial identifications poses the limiting bottleneck was not directly studied.

On the other hand, Valdois and colleagues have hypothesized that parallel rather than serial visual identification is impaired in dyslexia (e.g., Lassus-Sangosse, N'Guyen-Morel, & Valdois, 2008). However, in this case it seems fairly clear that they are talking about a distinct subtype of dyslexia. Indeed, they have found that visual attention span deficits can be dissociated from phonological deficits (Bosse et al., 2007), from magnocellular dysfunction (Prado, 2007; S. Valdois, personal communication, February 2012), and from sluggish attentional shifting (Lallier, Donnadieu, Berger, & Valdois, 2010; Peyrin, Demonet, N'Guyen-Morel, Le Bas, & Valdois, 2011), whereas both magnocellular dysfunction and sluggish attentional shifting tend to co-occur with phonological deficits (Lallier et al., 2009; Ramus, 2003). Thus, there may be no contradiction between the hypotheses of serial and parallel visual identification deficits; they may actually characterize different subtypes of dyslexia.

Learning
The failure to delineate a clear contrast between poor and normal performance along any specific auditory or visual dimension and the plethora of difficulties found across tasks and stimuli lead to the exploration of assessment procedures themselves. Thus, a subsequent line of studies focused on the dynamics of perception as a function of the context in which it was measured.

These studies manipulated the degree of cross-trial regularity rather than the tested stimulus dimensions or range of stimulus parameters. Since frequency discrimination was found impaired in dyslexia in several studies (described above), this dimension was explored using a series of different paradigms (M. Ahissar, Lubin, Putter-Katz, & Banai, 2006; Banai & Ahissar, 2006; Oganian & Ahissar, 2012). Notably, in one experiment, one of the two tones had a constant frequency across trials. This was intended to allow the auditory system to "anchor to" (implicitly detect) the repeated reference tone. The participant can thus perform the comparison by focusing on the variable tone and comparing it to the more stable memory trace of the reference

tone formed across several trials, hence improving performance. Indeed, in another experiment, there was no repetition across trials, thus a "real" comparison, based on active working memory, had to be implemented on every trial, and performance was overall lower. Dyslexic participants, whether with (M. Ahissar et al., 2006) or without (Oganian & Ahissar, 2012) a broader language impairment, benefited to a smaller degree than controls from the tone repetition. Thus, in these studies, the degree of regularity was contrasted, and while increased regularity made the task "easier", this was not as effective for the dyslexic population.

Similar findings were obtained when speech perception in noise was tested using either a small set of items that were repeated across trials or a large set in which each word was repeated only once or twice. A significant group difference was found only with the small set, when listeners could gradually form implicit expectations about the repeated words. Ahissar and colleagues (M. Ahissar, 2007; Banai & Ahissar, 2010) proposed that this aspect of fast learning, "anchoring", is impaired in dyslexia: specifically, the detection of sound regularities within a window of several seconds to minutes—that is, longer than the 2–3-second window of working memory. They interpreted these findings as indicating that dyslexics' performance is limited neither by the stimulus dimension (e.g., tone frequency) nor by its complexity, but rather by the efficiency of anchoring to recently presented stimuli. Similar discrepancies were reported by Heath et al. (1999), who found deficits in a fast two-tone identification test (the Tallal repetition test) only when the temporal interval was reduced in a gradual, adaptive manner (which is the typical mode of administration), which allowed participants to form specific expectations about the interstimulus interval.

Similar findings were also reported by Nittrouer, Shune, and Lowenstein (2011), who tested the sensitivity to spectral glides and speech in noise in a population of children selected for having phonological deficits. They found no difference in sensitivity to either spectral cues or

noise level. However, using an AX same–different paradigm, they found that children with phonological deficits had difficulties forming an internal reference for the repeated A stimulus and often had a higher tendency of answering "different" to an AA pair. Nittrouer et al. suggested that rather than having a basic perceptual deficit, these children may have difficulties forming categories based on consistently presented stimuli, which may affect the formation of phonological categories. Chandrasekaran et al. (2009) directly tested this hypothesis, by presenting syllables in noise under either a predictable, consistent context or a variable, inconsistent context. They found that repetition enhanced stimulus representation (subcortical auditory event-related potential, ERP, responses), but that this repetition effect was weakened in dyslexia. Similar results were found for poor readers (Strait, Hornickel, & Kraus, 2011). Oganian and Ahissar (2012) also measured the impact of repetition on reading rate and found that for controls, irregular words quickly become "regular" in a repeated context. However, dyslexics' reading rate was not "anchored" to local repetitions.

The relations between dyslexics' poor anchoring and their slower sequential identification described above are not clear. One option is that, as suggested by Kraus and colleagues (Chandrasekaran et al., 2009; Strait et al., 2011), repetition sharpens the representation (improves the signal to noise ratio) and hence facilitates the identification of repeated items. This sharpening being less efficient in dyslexia, identification is slower. Additionally, an effective detection of regularities may increase the effective size of perceptual units and hence decrease the number of required sequential identifications. For example, in two-tone identification, if the repeated tone is detected, only one identification is required in each trial (rather than two). Thus, when the reference tone is always lower than the nonreference (the standard psychophysical procedure), each of the two tones provides sufficient information for successful performance. If the reference is always presented first, it is sufficient to identify the second, nonreference, tone, which is indeed what

good listeners do (Nahum, Daikhin, Lubin, Cohen, & Ahissar, 2010).

The ability to automatically detect regularities has been shown at very young ages for the case of word segmentation, based on transitional probabilities between syllables, (e.g., Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). Anchoring may be needed for the ability to track such dependencies. Furthermore, difficulties with the detection of such regularities, for both speech and nonspeech sounds, has been associated with poor linguistic abilities, if not dyslexia per se (Evans, Saffran, & Robe-Torres, 2009).

Since the concept of anchoring has hardly been studied in the cognitive literature, the potential impact of poor anchoring within a window of seconds to minutes on the adequacy of long-term representations is not known and awaits further studies. Thus, in its initial formulation (M. Ahissar et al., 2006), the anchoring hypothesis did not predict poor phonological representations, only poor usage of these representations due to decreased benefit from the specific stimulation context (i.e., its regularities). Yet, it might be the case that poor anchoring could lead to poor long-term representations of those regularities (e.g., transitional probabilities) and hence might also lead to poor phonological representations.

In summary, the anchoring hypothesis proposes that dyslexics' "anchoring" memory is impaired, leading to inefficient usage of recent stimuli sequences and structures. Such impairment may lead to inefficient access to recently presented stimuli. Whether this putative deficit is expected to affect the adequacy of long-term representations—for example, phonology—should be the target of future research. More generally, our concern about overgeneralization and inaccurate prediction of poor performance potentially applies to the anchoring hypothesis as well. To this effect, it is important to emphasize that the anchoring hypothesis only applies to the auditory modality—indeed, attempts to find anchoring deficits in the visual modality have remained unsuccessful (M. Ahissar, unpublished data, 2012). Thus, the anchoring hypothesis specifically predicts that dyslexic individuals should perform

poorly in all auditory tasks that require extracting regularities within time scales on the order of seconds and minutes, but not necessarily in other modalities or at other time scales, and not in conditions where no such regularities are available to enhance task performance.

Similar patterns in other developmental disorders

The interesting patterns of poor and normal performance that we have just reviewed in the case of dyslexia are not without counterpart in other developmental disorders. Of course, to the extent that a developmental disorder is characterized by a specific cognitive profile (as opposed to uniform intellectual disability), there have to be areas of normal or at least less impaired performance. But recent findings would seem to suggest that some deficits are not necessarily what they were long thought to be. We discuss two examples familiar to us, congenital amusia and autism, with the hope of drawing interest to these issues for a broader range of disorders.

In the case of congenital amusia, a consensus had gradually emerged that this was to be explained by a core deficit in the representation of pitch (Peretz, 2008). However, one study exploring pitch short-term memory found that amusics were impaired in pitch memory beyond what could be predicted from their simple pitch perception deficit (Gosselin, Jolicoeur, & Peretz, 2009), which sounds quite similar to verbal short-term memory deficits in dyslexia. Furthermore, a recent study exploring different levels of pitch processing found that, while amusic individuals showed typically poor performance in tasks involving judging melodies with either out-of-tune or out-of-key notes, their ERPs to the deviant notes revealed an interesting contrast. Indeed amusic participants showed normal early negativities to notes that were mistuned by a quarter-tone. At the same time they showed disrupted late positivities to both out-of-tune and out-of-key tones (Peretz, Brattico, Järvenpää, & Tervaniemi, 2009). Thus, in the authors' own words, and contrary to their

expectations, "the presence of a mismatch negativity for mistuned pitches provides evidence that the amusic brain is sensitive to frequency of occurrence of fine-grained pitch differences in a musical context". They conclude that "the amusic brain appears to be more in tune than conscious perception reveals" (Peretz et al., 2009, p. 1283). In a striking parallel with Ramus and Szenkovits's (2008) analysis of the phonological deficit in dyslexia, it may well be that the problem in congenital amusia has more to do with accessing and manipulating pitch representations than with the representations themselves.

Turning to autism, there is a long tradition postulating that the core deficit lies in the representation of other people's mental states (Baron-Cohen, Leslie, & Frith, 1985; Leslie, 1987). Later theorizing has typically emphasized the existence of other deficits, but has not really challenged the existence of a metarepresentational deficit (Frith, 1989; Happé, 1999; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). Yet, many people have cautioned that poor performance in theory of mind (ToM) tests is open to multiple interpretations, including limitations in linguistic or executive abilities (e.g., Bloom & German, 2000). Most notably, studies on preverbal infants have shown the difficulty of inferring the absence of representations of others' mental states from poor performance in ToM tests (Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007), raising the very same methodological issues that we have highlighted here for dyslexia. Conversely, it has long been known that some individuals with high-functioning autism can eventually pass ToM tests, and again several interpretations have been offered for their normal performance (e.g., Happé, 1995).

In the meantime, other studies have provided evidence that people with autism show a diminished tendency to orient and attend to social stimuli (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998). In one notable study, adults with high-functioning autism were found to perform normally on an array of standard ToM tasks, yet their eye fixations revealed that they did not

spontaneously anticipate an agent's actions based on her false belief (Senju, Southgate, White, & Frith, 2009). Furthermore, a recent study provided evidence that adolescents with autism display a form of anhedonia with respect to social stimuli, but not to other sources of pleasure (Chevallier, Grèzes, Molesworth, Berthoz, & Happé, in press). In addition, an increasing range of studies have shown that the poor performance of autistic individuals in social cognition tasks can be dramatically improved by explicitly drawing their attention to the relevant social stimuli (see review by Chevallier, in press). Thus, just like in the dyslexia literature, autism research may be on the verge of shifting explanations from a deficit of representations of mental states, to a lack of spontaneous orienting or access to those representations.

Discussion

This review has highlighted, across a large range of tasks and several developmental disorders, the difficulty of interpreting poor performance in a given task. Tasks are deceptive. No matter how simple they seem, they involve multiple levels of representation and types of processing. It is therefore difficult to unambiguously attribute variance in performance to a particular level of representation or type of processing.

This ambiguity problem potentially affects all tasks. Here we would like to particularly draw the attention to perceptual tasks. Indeed these tasks are often believed to purely tap perceptual representations, as if the very notion of a "pure" task made sense. Thus, even a task as seemingly simple as frequency discrimination (saying which of two pure tones is higher) raises interpretation problems. Beyond the sheer resolution of frequency representations, performance in such a task also involves at least: (a) overall vigilance; (b) focused attention; (c) understanding and automatizing the mapping between frequencies and "high" versus "low" labels (or keys); (d) attention/conscious access to auditory representations (i.e., metacognitive processes); (e) auditory echoic and/or short-term memory; (f) auditory long-

term memory (when stimuli are familiar, for instance); (g) "anchoring"—that is, the ability to detect, learn, and exploit task structure and regularities to improve performance (for instance when one tone is kept constant).

In psychophysics, factors other than perceptual representations that may affect performance are not necessarily ignored, but they are at least experimentally neutralized, by selecting high-performing, well-behaving participants who are trained for hours (and who are able to focus their attention on a single task for that amount of time), so that in the end experimenters have reasonable grounds to assume that behavioural performance tells them something about participants' representations. But it is quite obvious that none of these conditions are met when testing pathological populations, let alone children. Thus a special group of participants may show poor performance by failing at a different locus from the one the task was designed to tap in normal participants. This is indeed what has been suggested in the case of categorical perception tasks, in which shallower identification curves and lower discrimination peaks in dyslexic participants may simply reflect more frequent lapses of attention (Davis, Castles, McAnally, & Gray, 2001; Roach, Edwards, & Hogben, 2004; Stuart, McAnally, & Castles, 2001).

Interpreting poor performance is difficult enough in the case of such a "simple" task as frequency discrimination; it may become inextricable in the case of more "complex" tasks such as those involving to a greater extent metacognition or working memory, which themselves are multilevel, multicomponent cognitive skills. What we are lacking at present are sufficiently precise models of these complex cognitive skills that would allow us to carry out careful task analyses and to determine which levels of representation and types of processing are shared by tasks and conditions in which patients perform poorly and are absent of tasks and conditions in which they perform normally. The notions of "phonological access" and of "anchoring" that we have previously proposed (M. Ahissar, 2007; Ramus & Szenkovits, 2008) should be seen as preliminary attempts in

this respect, soon to be superseded by more precise hypotheses once suitable models of metacognition, attention, working memory, and learning will be available.

In the meantime, one logical consequence of this critique should be to study developmental disorders using simpler tasks—that is, tasks that involve as few levels of representation and types of processing as possible, or at least that allow a more precise manipulation and control of these factors. The risk is of course to find normal performance, as indeed has been the case in many studies reviewed in the first section. However, we have argued that, to the extent that normal performance is not just a consequence of insensitive tasks and low statistical power, but can be reliably proven, it is as informative as poor performance, even though the interpretation of normal performance can be deceptive too (Karmiloff-Smith, 1998).

It is sometimes argued that the deficit is "subtle" (e.g., in dyslexia, but also in some types of aphasia and many other acquired disorders), so that tasks that are too easy run the risk of "missing" the otherwise hidden deficit. Such considerations lead one to increase the difficulty of tasks, for instance by adding noise to the stimuli, by presenting them in sequence so as to increase the short-term memory load, or by adding time pressure. However, it seems to us that relatively little thought has been given to the extent to which such difficulty factors alter the very nature of the task and the levels of representation and types of processing involved.

If deficits are too subtle for our simple tasks, then maybe the proper response should be to increase the subtlety and the sensitivity of our techniques. One option is to keep using simple tasks while manipulating experimental factors of which participants are totally unaware and on which the task does not bear and to look for interactions between group and the manipulated factor. This is indeed precisely what a number of studies that we have reviewed have done, some yielding surprisingly null (but informative) results (e.g., C. R. Marshall et al., 2010), others yielding intriguingly positive ones (e.g., M. Ahissar et al., 2006). Another approach is to use brain imaging

techniques to probe levels of representation or processing with minimal (if any) task demands— for instance, recordings of auditory cortical responses to sound under passive listening conditions (e.g., Lehongre, Ramus, Villiermet, Schwartz, & Giraud, 2011). The two approaches can, of course, be allied in order to measure modulations of brain responses by carefully chosen experimental factors, while again keeping task demands minimal. At any rate, the present review suggests that greater attention should be paid both to task difficulty factors that may degrade performance and to task regularities that may enhance it, and that when such factors are unavoidable, they should be explicitly manipulated, in order to uncover the specific role that they may play in task performance.

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