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Sequential *Versus* Simultaneous Processing Deficits in Developmental Dyslexia

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1. Introduction

Despite the large number of studies conducted on developmental dyslexia, the cause(s) of the disorder still remain(s) unclear. Researchers in this field still struggle to understand the reason why abnormal reading acquisition occurs in children who receive appropriate environmental opportunities to achieve a good education, and present normal intellectual efficiency. This introduction will focus on the presentation of the phonological hypothesis, and then move onto the presentation of the visual attention span hypothesis, which predicts at least two proximal causes to developmental dyslexia. Setting the theoretical framework for these hypotheses will help to understand why sequential and simultaneous dimensions for visual and auditory processing may have independent roles to play in typical and atypical reading development.

1.1 The phonological hypothesis: The only core deficit of the reading disorder

The phonological hypothesis (e.g., Snowling, 2000), probably the most well-known hypothesis among those formulated so far, predicts that an impairment in various phonological components (e.g., phonological short-term memory, phonological awareness, and phonological fluency) and sub-lexical processing (i.e., at the level of units smaller than the word such as graphemes, syllables or morphemes) would be detrimental for the acquisition of the skills necessary to decode new words, and acquire fluent reading (see Vellutino et al., 2004 for a review).

This hypothesis suggests that difficulties in acquiring phonological awareness and the alphabetic principle would prevent letter-to-sound mapping from developing normally. Consequently, a phonological disorder would affect reading acquisition, impairing the abilities necessary to map sub-lexical and lexical orthographic forms to their auditory counterparts. In support to the phonological deficit hypothesis, studies on typical children provided reliable evidence for a causal link between phonological skills development and reading acquisition (see however Castles & Coltheart, 2004 for a counter-argument about this causality). For example, longitudinal studies have shown that phonological skills predict later reading performance (e.g., Hulme et al., 2002). Phonology-based training

programs further showed a positive impact on reading acquisition (see Ehri et al., 2001 for a review). Such data strongly suggests that the role that phonological difficulties play in the reading disorder may indeed be critical.

However, studies have questioned the restriction of the difficulties of dyslexic participants to the verbal sphere, assuming that phonological disorders would themselves result from more basic perceptual processing difficulties. Such studies propose that perceptual difficulties might affect the rapid temporal dimension of processing characterizing phonological inputs. Thus, in order to highlight a link between these difficulties and reading problems, a large number of studies have attempted to define the nature of the temporal dimension of the deficits observed in dyslexic participants. In their review of the literature, Farmer and Klein (1995) described studies showing impaired performance in dyslexic participants not only in auditory but also in visual temporal processing. The authors concluded that a temporal amodal processing deficit is associated with developmental dyslexia and that the phonological disorder would result from this temporal processing deficit. Soon after their review, Farmer and Klein were reproached for having poorly defined and circumscribed the temporal deficits found in individuals with developmental dyslexia (Rayner, Pollatsek, & Bilsky, 1995).

Starting from Farmer and Klein (1995) and from the literature published since then, the following section will present three main research axes providing coherent choices of experimental paradigms and specific interpretative frameworks regarding temporal deficits in developmental dyslexia. However, these hypotheses greatly overlap with each other, and are not mutually exclusive.

1.1.1 The rapid temporal - *sequential* - processing deficit hypothesis

Before starting to detail the rapid temporal processing deficit hypothesis, note that here, *temporal* refers to the *sequential* dimension of processing, i.e., the succession of two or more stimuli, which underlies the notion of inter-stimulus interval (ISI). ISI corresponds to the period of time separating two visual or auditory objects presented sequentially. Therefore, the shorter the ISI, the more rapid the stimuli succession speed. It is important to note that this hypothesis also accounts for another type of temporal processing, a *transient* processing (temporal change within one stimuli) which specifically relates to the magnocellular hypothesis of dyslexia (cf 1.1.2). This section more specifically focuses on *sequential* aspects of temporal processing deficits in dyslexic participants since studies testing the rapid temporal processing deficit hypothesis of dyslexia have mainly assessed this specific type (i.e., sequential) of temporal impairments.

In line with the phonological hypothesis which posits that developmental dyslexia stems from a linguistic deficit (Vellutino et al., 2004), Tallal (1980) put forward a more general hypothesis accounting for an auditory processing deficit in dyslexia. Her underlying hypothesis is that the degradation of speech temporal analysis at the phonemic level causes the reading difficulties of dyslexic participants. More specifically, Tallal reasoned that dyslexic participants could not process the fast temporal changes in the speech signal, leading to degraded and noisy representations of linguistic sounds.

The results supporting this hypothesis first came from studies of specific language impairment (SLI) children who exhibit phonological problems, like dyslexic children. The

tasks used to assess the hypothesis of a general auditory disorder are temporal order and similarity judgment tasks. They involve the serial presentation of two phonological auditory stimuli and participants have to determine respectively which stimulus came first in the pair or whether the two stimuli were the same. Interestingly, deficits on these tasks were reported in SLI children only when the two stimuli were separated by a short time period; i.e., short ISI (e.g., Tallal & Piercy, 1973, 1974). Tallal's team then administered the same tasks to dyslexic children, but using non-verbal sounds such as pure tones. Deficits were reported in these children as compared to age-matched children but for ISIs shorter than 428ms (Tallal, 1980). A strong correlation was further found between dyslexic participants' performance on auditory temporal tasks and their pseudoword reading performance, thus providing first evidence for a link between rapid auditory sequential processing deficits and dyslexia.

Further evidence for a causal link between auditory and reading disorders was provided by Benasich and Tallal (1996), assessing performance of 7.5 month old infants considered "at risk" for a future language disorder on a task where participants had to distinguish various acoustic features presented at a fast rate. The performance of the infants on the task explained a significant part of variance in their later language skills and predicted a language impairment at 3 (Benasich & Tallal, 2002, see also Hood & Colon, 2004). Coupled with neuroimaging data, some training studies of auditory rapid sequential skills supported such causal link (e.g., Habib et al., 2002).

While many studies showed auditory rapid sequential processing deficits in dyslexic individuals using either verbal (e.g., De Martino, Espesser, Rey, & Habib, 2001; Heim, Freeman, Eulitz, & Elbert, 2001) or non-verbal (e.g., Laasonen, Service, & Virsu, 2001) stimuli, other results questioned the restriction of the impairment to rapid stimuli sequences. Indeed, some studies failed to reveal a deficit in dyslexic participants on the short ISI conditions only (Bretherton & Holmes, 2003; Chiappe, Stringer, Siegel, & Stanovich, 2002; Ram-Tsur, Faust, & Zivotofsky, 2006). Others found that dyslexic individuals were impaired for long intervals as well, even when using the same tasks as Tallal (Share, Jorm, Maclean, & Matthews, 2002). It follows that auditory rapid sequential deficits may not be a condition sufficient and necessary to observe dyslexia. Nevertheless, available data suggests that such rapid sequential auditory processing plays a role in normal reading (Au & Lovegrove, 2001a, 2001b) and phonological development (Walker, Hall, Klein, & Phillips, 2006).

It has also been suggested that the phoneme processing difficulties of dyslexic participants could well be part of a more general, amodal, rapid sequential processing deficit (the "rate processing deficit" hypothesis) by introducing the hypothesis of a similar impairment in the visual modality. Regarding visual *sequential* processing deficits, studies reported that as compared to controls, dyslexic individuals required longer ISIs in order to be accurate on spatial-temporal order judgment tasks, either with verbal (May, Williams, & Dunlap, 1988) or non-verbal (Hairston, Burdette, Flowers, Wood, & Wallace, 2005; Jaskowski & Russiak, 2008) visual stimuli. In these tasks – similar to those described previously in the auditory modality- participants are presented with pairs of visual stimuli appearing sequentially on a screen at different locations, and have to decide which of the two stimuli was displayed first.

As with in the auditory modality however, findings revealed that visual temporal order judgment impairments of dyslexic participants did not depend upon the ISI duration (Ram-

Tsur et al., 2006; Ram-Tsur, Faust, & Zivotofsky, 2008). Some studies even failed to show any disorder of this kind (Laasonen Tomma-Halme, Lahti-Nuuttila, Service, & Virsu., 2000, Lassonen et al., 2001). Supporting the idea of a weak link between visual sequential processing and reading, Hood and Conlon (2004) failed to show that visual temporal order judgment performance of preschoolers predicted their reading skills at Grade 1 (see also Landerl & Willburger, 2010 for similar results in both the visual and the auditory modality). However, Walker et al. (2006) showed that such performance significantly contributed to reading performance and phonological awareness abilities in a large sample of young and older adults with various reading levels.

Despite attempts to highlight an amodal rapid sequential processing deficit, very few studies have actually measured visual and auditory rapid sequential processing in the same dyslexic participants using similar paradigms (e.g., Laasonen et al., 2000, 2001; Reed, 1989). Overall, previous studies question the sequential visual impairment but the nature of the auditory processes that have been captured by the order judgment task (e.g., deciding which of two stimuli displayed sequentially appeared first) and similarity judgment task (e.g., deciding whether two stimuli presented sequentially were the same or not) still needs to be clarified (see Bailey & Snowling, 2002). Lastly, this hypothesis tends to predict a relation between visual rapid sequential processing and lexical reading, i.e., regular word or irregular word reading, but *a priori* no link with phonological processing, which is hard to reconcile with the phonological hypothesis of developmental dyslexia. Pointing out these problems, Stein and Talcott (1999) reminded that the rapid sequential processing deficit hypothesis was first grounded on temporal order and similarity judgments, which, according to them, cannot capture the temporal processing required for phonological representation build-up.

1.1.2 The magnocellular hypothesis: The "Impaired Neuronal Timing" hypothesis (Stein & Talcott, 1999)

The magnocellular hypothesis of dyslexia (Stein & Walsh, 1997; Stein & Talcott, 1999) supports the idea of visual and auditory perceptual deficits which specifically account for *transient* or *dynamic* aspects of temporal processing (i.e., rapid physical changes in real time within a stimulus). To a lesser extent, it relies to the ability to process distinct stimuli when presented serially, in sequences (see 1.1.1). Stein and Talcott (1999) claimed that sensitivity to transient events could be assessed with simple stimuli triggering the activation of neurons specifically devoted to that type of processing: the magnocellular cells. The authors assume that magnocellular cells which are part of both the visual and the auditory human systems would dysfunction in dyslexic participants (vision: Livingstone, Rosen, Drislane, & Galaburda, 1991; audition: Galaburda, Menard, & Rosen, 1994). In that sense, the magnocellular hypothesis of dyslexia differs from the rapid sequential processing deficit hypothesis because the latter does not specify any cerebral origin to the auditory and visual deficits of individuals with dyslexia.

Originally, the magnocellular hypothesis builds its foundation on the organization of the visual system and leans onto three main ideas:

1. The existence of two independent neural pathways, located deep below the surface of the brain (sub cortical structures), called the magnocellular and parvocellular pathways. Interestingly, the magnocellular system – called also *the transient system* - is tuned in to

fast temporal processing, whereas the parvocellular system is more sensitive to slower temporal processing – *sustained system*[1]);

2. The observation of these two neural pathways at the surface of the brain, (i.e., in the cerebral cortex, which plays a key role in language) via two routes called the dorsal and ventral routes respectively;

3. The dorsal route starts from the visual primary brain areas (V1) to the visual motion brain areas (MT/V5) to finish on the posterior parietal cortex, that subtends to visual selective attention and ocular movement monitoring (important in reading).

In the visual modality, the magnocellular hypothesis predicts impaired monitoring of ocular movements, leading to visual confusion, superposition and distortion during reading. In the auditory modality, a similar organization is found with the existence of two cortical routes (Clarke, Bellmann, Meuli, Assal, & Steck, 2000). Moreover, the "magnocellular" auditory neurons have been shown to be specialized in the tracking of amplitude and auditory frequency (pitch) changes within acoustic signals (Trussel, 1999). According to Stein and Talcott (1999), a phonological disorder would result from auditory transient, very fast, temporal processing difficulties. Therefore, both visual and auditory transient processing deficits would together yield a degradation of grapheme-to-phoneme mapping processes and sub-lexical reading and decoding (Pammer & Vidyasagar, 2005).

Data on behavioral tasks involving processing changes within stimuli have supported the visual transient processing deficit hypothesis of developmental dyslexia. It was indeed shown that dyslexic participants required more time to perceive the dynamic change within stimuli (McLean et al., 2011). The most commonly used tasks for revealing transient processing differences between dyslexic individuals and controls involve the detection of either a transient change in the identity of the stimulus (e.g., a single visual dot becoming two flashing dots at the same location: Edwards et al., 2004; Van Ingelghem et al., 2001), a transient change in the spatial location of the stimulus (e.g., when a visual object is moved to a different location: Jones, Branigan, & Kelly, 2008) or a transient change in the way a group of stimuli moves (e.g., when the direction of the movement of a group of visual dots changes: Cornelissen, Richardson, Mason, Fowler, & Stein, 1995). Supporting the magnocellular hypothesis deficit, visual transient processing deficits have been linked to sub-lexical reading deficits in participants with dyslexia (e.g., Cestnick & Coltheart, 1999). However, the link between visual transient processing and reading was not always established in skilled readers (e.g., Au & Lovegrove, 2001a). Moreover, strong inconsistencies have still been reported with some studies showing no such visual deficits in dyslexic participants (e.g., Amitay, Ben-Yehudah, Banai, & Ahissar, 2002; Ben-Yehudah, Sackett, Malchi-Ginzberg, & Ahissar, 2001).

In the auditory modality, a transient processing deficit has also been reported with experimental paradigms similar to the ones used in the visual modality, such as silent gap detection or segregation tasks (when participants have to detect a silence inserted within an auditory stimulus: Helenius, Salmelin, Service, & Connolly, 1999), the apparent movement task (when auditory tones moves from one hear to the other: Hari & Kiesilä, 1996 but see

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[1] Note that the magnocellular system preferentially responds to low spatial frequencies and is very sensitive to luminance contrasts. For the purpose of the present chapter, we will specifically focus on the *temporal transient* processing deficits in relation to reading disorders and reading development.

Kronbichler, Hutzler, & Wimmer, 2002), or pitch and amplitude modulation discrimination tasks (when auditory stimuli progressively change in loudness or pitch: Witton, Stein, Stoodley, Rosner, & Talcott, 2002). Phonological skills (Talcott et al., 2000, but see Kidd & Hogben, 2007) and pseudo word reading (Au & Lovegrove, 2001a, 2001b, 2008; Walker et al., 2006; Witton et al., 2002) performance has further been linked to auditory transient (i.e., magnocellular) performance. Some data further suggests a potential causal link between auditory transient processing and phonological skills (Schäffler, Sonntag, Hartnegg, & Fischer, 2004).

However, it still remains that a phonological deficit does not always accompany difficulties in auditory or visual transient processing (Heim et al., 2008; Kronbichler et al., 2002; Ramus et al., 2003; White et al., 2006). The hypothesis of a role of these deficits in the reading disorder has been criticized particularly in the visual modality and such visual deficits have been considered as an epiphenomenon associated with reading difficulties (e.g., Hutzler, Kronbichler, Jacobs, & Wimmer, 2006; Skottun, 2000).

Interestingly, in their original proposal, Stein and Talcott (1999; Stein & Walsh, 1997) suggest that the link between magnocells dysfunction and developmental dyslexia is mediated by poor ocular movement monitoring because of the projection of magnocells to the posterior parietal cortex in charge of such visual-motor control skills. From that perspective, it has been proposed that the reading disorder may rather result from a parietal dysfunction than from the degradation of magnocells *per se* (e.g., Boden & Giaschi, 2007). Along these lines, Buchholz and MacKone (2004) concluded that phonological awareness and visual attention skills – subtended by parietal activation – are related, whereas phonology and magnocellular processing *per se* are not. This new perspective based on attentional processing will result in a new proposal explaining the cause of developmental dyslexia, favoring the role of the parietal cortex in the amodal temporal processing deficits associated with the reading disorder (Hari & Renvall, 2001).

1.1.3 The sluggish attentional shifting hypothesis

According to Hari and Renvall (2001), the magnocellular dysfunction at the cell level could lead to a variety of symptoms (including the reading disorder) which would depend on what cerebral structure is the most impaired by the magnocellular dysfunction. From that perspective, the type of temporal processing affected would not be specific to magnocell characteristics but would be supported by the cerebral structure the most affected by the magnocell dysfunction. In the sluggish attentional shifting (SAS, hereafter) hypothesis, Hari and Renvall (2001) propose the parietal cortex as the structure responsible for the reading disorder (see Figure 1 for a schematic representation of the links between the magnocellular and the SAS hypotheses in relation to reading disorders).

According to these authors, the parietal dysfunction would affect the automatic processes engaged in attentional shifting over rapid stimulus sequences in all sensory modalities (auditory, visual, and tactile). In that sense, the SAS hypothesis stands at the crossroad between the rapid sequential (perceptual) processing deficit hypothesis (see section 1.1.1) and the magnocellular deficit hypothesis of developmental dyslexia (see 1.1.2). Hari and Renvall (2001) described precisely the temporal dimension their theory accounts for and emphasized that this specific temporal processing relates, on the one hand, to the processing

of *distinct successive stimuli*, and, on the other hand, to the processing of distinct changes within a *stimulus sequence* (rather than within a single stimulus).

Therefore, the SAS hypothesis does not make predictions about, for example, auditory frequency or amplitude modulation detection described by the magnocellular deficit hypothesis. Hari & Renvall (2001) propose that SAS is "*the pathophysiological link between the magnocellular deficit and the RSS* [Rapid Stimuli Sequence] *processing in dyslexic subjects*" (p.530). In this framework, a magnocellular dysfunction would not be a factor sufficient and necessary to observe dyslexia (Skoyles & Skottun, 2004) although magnocellar deficits would still potentially be associated with manifestations of reading difficulties. Rather, Hari and Renvall assume that the parietal dysfunction would be responsible for reading disabilities, via SAS skills.

The principles of the SAS hypothesis are the following: when a to-be-processed stimulus is perceived, it falls into a perceptual temporal window whose size depends upon how fast the cognitive system can integrate this stimulus. According to Hari and Renvall (2001), the time of integration would be prolonged in individuals with developmental dyslexia. When several stimuli are sequentially presented, the prolongation of the integration time would create interferences between the stimuli entering the temporal window and induce a prolonged perceptual persistence in dyslexic individuals (e.g., Slaghuis & Ryan, 1999). It is therefore inferred that dyslexic participants would show difficulties in automatically disengaging the focus of attention from one stimulus to reengage it on the next one.

In order to justify the specific attentional (and not perceptual) origin of the deficit, Hari and Renvall (2001) argue that 1) dyslexic participants do not exhibit any deficit regarding the temporal synchronization between the moment when stimulus is presented and its actual processing by the neuronal system (*phase locking*: Hari, Saaskilahti, Helenius, & Uutela, 1999a; Llinas, 1993; Witton, Richardson, Griffiths, & Rees, 1997) and 2) the SAS hypothesis can account for two attention phenomena known to be linked to reading, namely the attentional dwell time and the symptom of hemineglect. These two phenomena are explained below:

i. The attentional dwell time has been reported in all sensory modalities in paradigms where stimuli are rapidly and serially presented (in vision: Raymond, Shapiro, & Arnell, 1992; in audition: Vachon & Tremblay, 2008). The attentional dwell time is a theoretical concept corresponding to a natural limit in attentional resources reflected by the interference induced when several stimuli fall into the same temporal integration window. Specifically, the attentional dwell time is thought to cause difficulties in processing a target falling into the same temporal integration window as a first previous target to which most attentional resources have been already allocated. This drop in performance for the second target processing would spread from 300ms to 500ms after the presentation of the first target depending on the experimental paradigm and/or the sensory modality. According to Hari and Renvall (2001), this natural limit in temporal attention resources would be stronger in individuals with developmental dyslexia because of their SAS skills. Hence, in dyslexic participants, the combination of SAS skills and attentional dwell time would lead to a prolongation of temporal input chunks falling under the attentional focus. The length of these inputs would increase their complexity, inducing poor encoding of visual or auditory sequential stimuli at

higher levels (such as graphemic –letter- or phonemic –language sounds-representations).

ii. Furthermore, based on the observation that visual heminiglect patients[2] exhibit a prolongation of the attentional dwell time (Husain, Shapiro, Martin, & Kennard, 1997), Hari and Renvall (2001) proposed the left visual minineglect as a marker of developmental dyslexia, but not as a causal factor. From that perspective, this left minineglect would result from a dysfunction, and not a lesion, of the right parietal cortex (Hari, Renvall, & Tanskanen, 2001; Liddle, Jackson, Rorden, & Jackson, 2009). Supporting this idea, dyslexic children have been shown to suffer from left pseudoneglect, i.e. presenting symptoms of left hemineglect patients, in absence of any parietal lesion. The typical behavioural marker for this left pseudoneglect is the absence of the usual overestimation (facilitation for processing) of stimuli presented in the left visual hemifield (Sireteanu, Goertz, Bachert, & Wandert 2005; Sireteanu, Goebel, Goertz, & Wandert, 2006).

Along the same lines, data collected in dyslexic individuals are in accordance with an asymmetric distribution of attention resources between right and left visual hemifields (e.g., Facoetti & Moltoni, 2001; Facoetti Paganoni, Turatto, Marzola, & Mascetti,, 2000; Facoetti & Turatto, 2000). Indeed, Facoetti's team studies show that participants with developmental dyslexia exhibit higher inhibition for the stimuli displayed in the left visual field but a facilitation of processing for those displayed in the right visual field. Moreover, it has been shown that training programs involving specific stimulation of each hemisphere individually (tachitoscopic presentation of words) improved not only the visual-spatial attentional skills of dyslexic readers in the right hemisphere/left hemifield (Facoetti, Lorusso, Paganoni, Umilta, & Mascetti, 2003; Lorusso, Facoetti, Toraldo, & Molteni, 2005) but also their reading performance (Lorusso, Facoetti, & Molteni, 2004; Lorusso et al., 2005). Note that lesions in the posterior parietal cortex can also induce auditory neglect (Marshall, 2001), the SAS hypothesis predicts similar impairment in the auditory modality.

Regarding the link between visual and auditory SAS and reading, Hari and Renvall (2001) assume that a phonological disorder would result from auditory SAS. Indeed SAS is expected to cause longer and more complex phonological input chunks, thus hindering the build-up of stable phonological representations. The link between visual SAS skills and reading is clearly explained (i.e., because the number of letters that participants have to encode during one ocular fixation during reading is increased, interferences and possible confusions in reading are observed) but their responsibility in the phonological disorder is not described. However, one can assume that both visual and auditory SAS would be linked to phonological deficits via their contribution to the acquisition of the grapheme-phoneme correspondences that are indispensable for normal reading acquisition (Pammer & Vidyasagar, 2005; Vidyasagar & Pammer, 2010).

The SAS hypothesis therefore offers an explicative framework for verbal and non-verbal auditory and visual attention sequential deficits. It furthermore specifies the

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[2] Hemineglect patients typically suffer from a parietal lesion (interpreted as an attentional deficit at the cognitive level) which causes difficulties in encoding and processing visual object appearing in the hemifield in the opposite side of this parietal brain lesion (e.g., impairment of processing visual object appearing on the right side visual field due to a lesion in the parietal lobe of the left part of the brain).

neurophysiologic cause and specific cerebral locus of the reading disorder. In this framework, developmental dyslexia is still viewed as resulting from a phonological disorder, which however would be associated with additional visual attentional deficits whose role in reading difficulties still remains unclear.
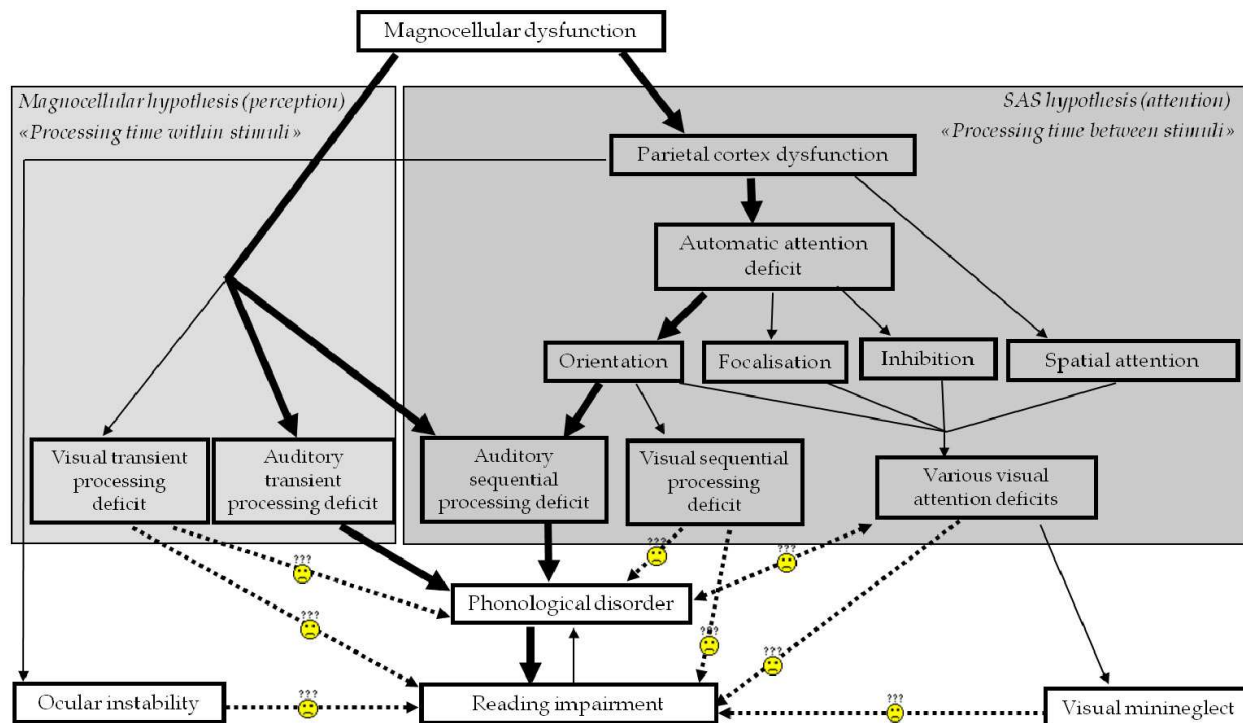

Fig. 1. Schematic syntheses of the causal cascade (plain arrows) suggested by the magnocellular and the SAS hypotheses. Dotted simple arrows represent causal links and dotted double arrows associative links as suggested in the literature but which have been questioned. Note that the SAS hypothesis explains many symptoms associated with developmental dyslexia. Adapted from Lallier (2009).

1.2 The visual attention span deficit hypothesis: Developmental dyslexia as a cognitive multifactorial disorder

So far we have reviewed hypotheses that have been put forward in order to explain developmental dyslexia as resulting from a phonological disorder. However, it appears that at least some dyslexic cases are clearly not phonological (Friedmann & Naachman-Katz, 2004; Friedmann & Rahamin, 2007; Rouse & Wilshire, 2007; Valdois et al., 2003; Valdois, Lassus-Sangosse, & Lobier, In press), thus questioning the homogeneity of developmental dyslexia. Instead, a growing body of evidence suggests that developmental dyslexia is heterogeneous (e.g., Heim et al., 2008).

The visual attention span (VA Span hereafter) hypothesis put forward by Bosse, Tainturier and Valdois (2007) is complementary to the phonological deficit hypothesis. It posits that another cause of developmental dyslexia stands in a limitation of the visual attention resources that can be allocated simultaneously to letters within words. This would in particular prevent normal encoding of whole word orthographic information. The VA Span therefore taps into parallel, simultaneous, processing, and VA Span resources are expected to be limited in at least a subgroup of dyslexic children.

The VA Span is a notion theoretically motivated by the Multi-Trace Memory model of reading (Ans, Carbonnel, & Valdois, 1998; hereafter MTM model). The MTM model was the first reading model to implement a visual attention component, called the visual attentional window (which is the counterpart of the VA Span in human participants). The VA window is a critical component of the reading system as it delineates the amount of orthographic information which is under the focus of attention at each step of the reading process. The MTM model postulates that reading relies on two global (parallel) and analytic (serial) procedures that differ regarding the visual attention window size, and therefore, regarding VA Span skills and the quantity of visual attention devoted to processing. In global mode, the window opens over the whole letter string whereas in analytic mode, it narrows down to focus attention on each orthographic sub-unit of the input word in turn. Although these two procedures are *a priori* not devoted to reading specific item types, most familiar items (in particular previously learned words) are processed in global mode whereas non-familiar items (most pseudowords) are processed in analytic mode. The visual attentional window therefore corresponds to the set of visual elements over which the visual attentional focus falls.

Following this theoretical framework, it was reasoned that a VA Span reduction (i.e., a reduction of the number of visual letters that can be processed simultaneously) should prevent normal encoding of the orthographic sequence of most words (Bosse et al., 2007). According to this idea, a reduced VA Span would be particularly detrimental when reading irregular words that cannot be accurately decoded serially.

The VA Span is typically measured using whole and partial letter report tasks which require naming all of the letters of a five-consonant string or a single post-cued letter within the string (see Fig 2). In partial as in global report, participants have to process all five consonants since the position of the letter to be reported is randomly chosen and the cue in partial report only occurs at the offset of the consonant string. Moreover, sequences are displayed for a time period short enough to avoid useful ocular saccades (<200ms), so that participants have to engage enough visual attention resources to process all five elements simultaneously (Lobier, Przybylski, & Valdois, Submitted; Peyrin, Lallier, & Valdois, 2008; Peyrin, Démonet, N´Guyen-Morel, Le Bas, & Valdois, 2011). Only consonants are used as stimuli to compose unpronounceable illegal letter strings. In random consonant strings, identification of one consonant within the string does not help identifying the other consonants, so that the number of reported letters provides a good account of the number of distinct elements that can be processed simultaneously. To avoid any potential top-down influence of orthographic knowledge on performance, the consonant strings we use do not include any multi-letter grapheme or frequent bigram (as CH or FL in French). Moreover, sequences do not correspond to the skeleton of any word (e.g., C M P T R for computer), since we know that such consonant strings activate the corresponding word orthographic information in long term memory. In the whole report task, the five elements need to be verbally reported without order constraint whereas in the partial report task the cued letter alone has to be reported. Accordingly, responses as "RHSDM", "SDHRM" or "DSRMH" are all considered as accurate (quoted 5/5) for the "RHSDM" input in global report, since all five consonants have been accurately identified in all three cases. A deficit on such tasks is reflected by a poor accuracy report score, interpreted as a reduction of the VA Span.
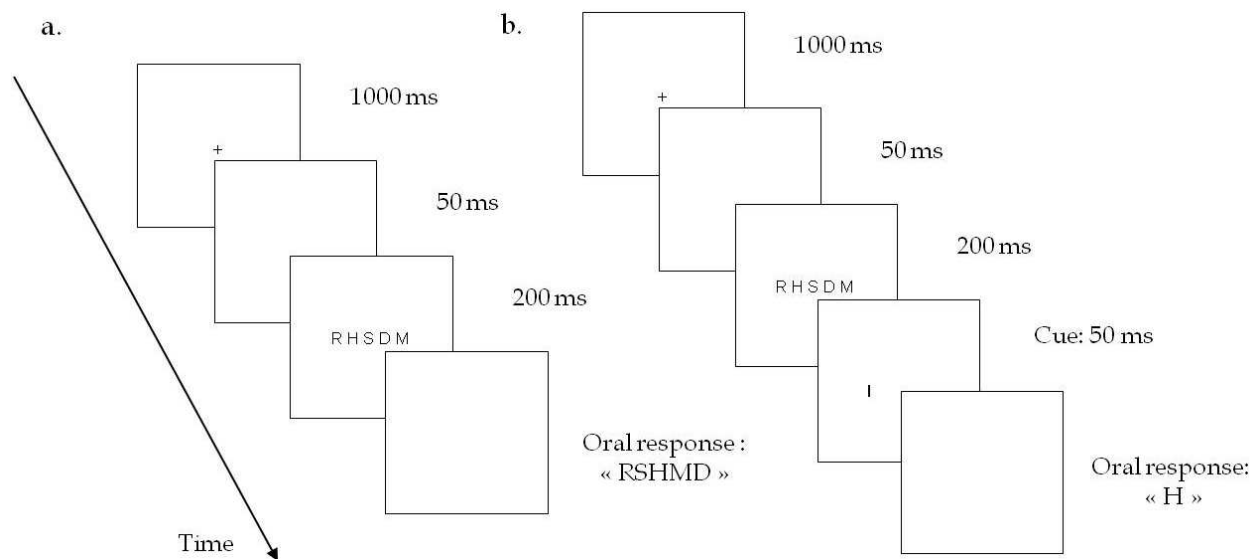
Fig. 2. Schematic illustration of the whole and partial report tasks. The whole report task requires naming as many of the 5 consonants as possible without order constraint (a.). The partial report task requires a single cued letter to be named (b.).

The link between VA Span skills and reading has been observed in a group study conducted in two populations of dyslexic children (68 French speaking dyslexic children and 29 English dyslexic children) whose performance was compared to age-matched children (Bosse et al., 2007). All children were given a screening battery comprising reading tasks, phonological awareness tasks and the whole and partial report tasks. Results showed that a large part of dyslexic children exhibited either a specific and selective phonological deficit or a specific and selective VA Span deficit. On the other hand, a smaller group of children exhibited a double deficit (i.e., on phoneme awareness *and* visual letter report tasks). Moreover, the results of the study in French speaking children revealed that both phonological and VA Span skills independently explained a significant part of variance in reading performance. The study in the English speaking children confirmed that VA Span skills contribute to reading abilities even when non verbal IQ, verbal fluency skills, vocabulary and the performance on a single letter identification task are controlled for. Bosse et al. (2007)'s findings therefore suggest that at least two independent cognitive disorders underlying developmental dyslexia can be observed. Their conclusion is furthermore supported by a case study in two French dyslexic teenagers showing that a reading disorder of the same severity could either be accompanied by a phonological disorder (rhyme judgment, sound categorization, phoneme and syllable omission, phoneme segmentation, acronyms) associated with a phonological dyslexic profile (impaired decoding skills illustrated by poor pseudoword reading and spelling skills) in the absence of any VA Span deficit on the two report tasks, *or* by a VA Span disorder associated with a surface dyslexia profile (poor lexical reading procedure illustrated by poor word reading and spelling) with no additional phonological disorder (Valdois et al., 2003).

The role of VA Span skills in normal reading development was investigated in a cross-sectional study conducted on large samples of typically developing children from 1st to 5th grade (Bosse & Valdois, 2009). Results showed that VA Span abilities contributed to reading performance from the early stages of literacy instruction even after controlling for variations

in phonological performance. Indeed, the unique contribution of VA Span to reading performance was observed from the first year of literacy instruction at a time phoneme awareness skills played an important (but independent) role in reading acquisition. Furthermore, VA Span performance contributed preferentially to irregular word reading (i.e., word-specific orthographic knowledge) as compared to pseudoword reading.

Moreover regarding spelling abilities, the findings of Valdois and Bosse (Submitted) in 1st, 3rd and 5th graders strengthen the role of VA Span skills in orthographic knowledge acquisition. These authors show that VA Span skills and phonological skills independently contribute to the acquisition of orthographic knowledge. Moreover, VA Span contribution to word spelling accuracy remains even after accounting for the children's recoding skills. This suggests a role of VA Span in the acquisition of word specific orthographic knowledge. VA Span contribution to word spelling is more stable than phoneme awareness contribution over grades, suggesting a long-term influence of the VA Span on the acquisition of orthographic knowledge. In sum, a large body of data from dyslexic and typically developing children supports a role of the VA Span in reading and spelling. The overall data points to the involvement of VA Span in the acquisition of orthographic knowledge and suggests this visual attention mechanism may act as a self-teaching device process.

The VA Span hypothesis postulates that the component preventing dyslexic individuals from performing accurately a multi-element array of stimuli does not relate to any type of verbal or phonological disorder but rather, to visual attention (Bosse et al., 2007; Peyrin et al., 2011). It has however been argued that poor performance in letter report tasks might be due to verbal deficits in encoding and reporting letters, and as such reflected a visual-to-phonology code mapping disorder (Ziegler, Pech-Georgel, Dufau, & Grainger, 2010) rather than a visual attention resource limitation. Ziegler et al. (2010)'s account is based on data from a forced choice detection task in which children were shown briefly presented strings of letters, digits or symbols. At the offset of the multi-character string, participants had to choose which one of two characters previously occurred in a cued position within the string. Results showed that dyslexic children performed poorly when asked to process letter or digit strings but at the level of control children when processing symbol strings. The authors reasoned that a VA Span disorder would have predicted a deficit whenever multi-element parallel processing is required independently of the nature (alphanumeric or not) of the stimuli. Against this expectation, their data showed that the disorder was restricted to alphanumeric material. They thus concluded that their findings did not support the VA Span deficit hypothesis but rather suggested a visual-to-phonological code mapping disorder.

It is however noteworthy that the letter/digit *versus* symbol character not only differ in their phonological characteristics (pronounceable *versus* non pronounceable characters) but also in the visual ones (familiar *versus* unfamiliar visual shapes), so that differences in processing might follow from one or the other dimension.

Against the phonological account, data shows that:

- a visual-to-phonological code mapping interpretation cannot account for the whole data set;
- the VA Span disorder extends to non-verbal tasks and non-verbal material.

With respect to the first point and against the visual-to-phonological code mapping disorder interpretation, Valdois et al. (In press) showed that dyslexic children are not systematically

impaired in tasks involving visual-to-phonological code mapping. Dyslexic and control children were asked to perform a 5-elements report task using letters, digits and color patches as stimuli. All three conditions required verbally reporting as many letter, digit or color names as possible at the offset of the multi-element string. Accordingly a visual-to-phonological code mapping disorder was expected to impact all three conditions. Against this expectation however, dyslexic participants were found to exhibit poor performance in letter and digit string report tasks but no disorder in the color string report task. This result goes against the visual-to-phonological code mapping disorder hypothesis.

Moreover, Valdois et al. (In press) reported a second experiment in which dyslexic children were administered two versions of the whole letter report task. Both conditions required the oral report of all five letter-names at the end of processing but the whole report task was either performed alone or together with a concurrent phonological articulation task (i.e., of counting aloud). The concurrent articulation task taxed phonological processing and verbal short-term memory and as such prevented online verbal encoding of letter names during visual processing. Dyslexic children exhibited a similar VA Span deficit in the two conditions, suggesting that performance was not modulated by on line verbal encoding. This last result suggests that difficulties of dyslexic participants on the whole report task do not result from a verbal encoding deficit.

Moreover, Lobier, Lassus-Sangosse, Zoubrinetzki, and Valdois (In press) administered a categorization task which required parallel processing of multi-elements within strings to a group of dyslexic children selected for their poor performance in visual letter report tasks. The categorization task involved the processing of verbal (digits and letters) *or* non-verbal (Japanese Hiragana characters, pseudo letters, and unknown geometrical shapes) characters. The study aimed to assess whether this group of dyslexic children exhibited similar difficulties in the processing of alphanumeric and non-alphanumeric character strings. The dyslexic participants with a VA Span deficit were found to be impaired on the visual categorization task regardless of whether the stimuli to be processed were verbal or non-verbal. They were thus impaired in a non-verbal task using non-verbal stimuli as they were found impaired in the letter report task. Taken together, these results provide strong evidence against a phonological account of poor letter string processing and VA Span skills in developmental dyslexia.

The currently available neurobiological data collected during parallel multi-element processing are well in line with the VA Span interpretation. Data from adult skilled readers showed that the letter report task elicited increased activation of the superior parietal lobules bilaterally and that activation of these regions was reduced in the dyslexic participants (Peyrin, et al., 2008). In another study carried out on dyslexic and non-dyslexic children, participants were administered a categorization task comprising two isolated and flanked conditions (inspired from Pernet, Valdois, Celsis, & Démonet, 2006) under fMRI (Peyrin et al., 2011). In both conditions, two stimuli – either two letters or two geometrical shapes or one of each – were simultaneously displayed, one stimulus was centrally presented on the fixation point, the other one was randomly presented in the right or left visual field. In the flanked condition, the peripheral stimulus was flanked with two "X"s whereas it was presented alone in the isolated condition. Participants had to decide whether the two stimuli belonged to the same category or not. Results replicated previous findings in showing that VA Span impaired dyslexic children were characterized by reduced

activations within the superior parietal lobules bilaterally (Peyrin et al., 2011). Thus, multi-element parallel processing relies on brain regions that are well known for their involvement in visual attention. More recently, Lobier et al. (Submitted) investigated whether these parietal regions were sensitive to the alphanumeric or non-alphanumeric nature of the stimuli. They administered a non-verbal categorization task under fMRI using either letters or digits as targets, or pseudo-letters, shapes and hiragana characters. They found that the superior parietal lobules were involved in the processing of both alphanumeric and non-alphanumeric character strings and that activity in these regions was reduced in dyslexic individuals regardless of character type (i.e., strings composed of alphanumeric or non alphanumeric elements).

The overall results of the series of studies of Valdois'team thus support the existence in a subset of dyslexic individuals of a parallel multi-element processing disorder, i.e. a VA Span disorder, that relates to a superior parietal lobules dysfunction and dissociates from phonological problems.

2. SAS *versus* VA Span hypotheses: Sequential *versus* simultaneous processing deficits in dyslexia

We previously presented a set of hypotheses that sought to explain the cognitive origin of developmental dyslexia. The first part was devoted to the description of the phonological hypothesis which postulates that reading difficulties result from a specific impairment affecting the processing of phonological stimuli, then resulting in difficulties in mapping graphemes to phonemes during reading. Among the hypotheses presented, the SAS hypothesis postulates a deficit at the attentional level which would then lead to developmental reading disorders.

In the second part, we presented a multifactorial view of the cause of developmental dyslexia: the VA Span hypothesis. This hypothesis assumes that atypical reading development can either stem from a phonological deficit, or a visual attention deficit affecting the simultaneous processing of multiple visual stimuli. In preventing simultaneous processing of letters within the word string, the VA Span disorder is expected to prevent normal encoding of whole word forms, thus leading poor word-specific orthographic knowledge acquisition.

It is noteworthy that the type of attention processes described in the SAS and the VA Span hypotheses corresponds to what could be named "perceptual" or "automatic" attention. Such attention processes are thought to facilitate the processing of stimuli falling under the focus of attention during the first 200-250 msec after engagement of the attentional focus.

Looking at the SAS and VA Span hypotheses more carefully, we can observe that they offer complementary accounts for developmental dyslexia. While they both assume that a parietal dysfunction is the cerebral origin of the reading disorder, the two hypotheses differ in the sense that the parietal impairments described would lead to distinct, independent, cognitive deficits: a phonological deficit for the SAS hypothesis, and a visual attention deficit for the VA Span hypothesis. Moreover, it is assumed that the mechanisms underlying phonological and VA Span processing would *a priori* engage distinct dimensions of processing: one sequential, and the other simultaneous.

Interestingly, the SAS and VA Span hypotheses both predict visual attention problems in developmental dyslexia, but while the VA Span hypothesis assigns to the visual attention disorder a causal role in developmental dyslexia, the SAS hypothesis rather predicts an association between reading and sequential visual attention skills than a causal relationship, unlike what is posited in the auditory modality. Furthermore, the SAS hypothesis predicts sequential attention deficits in both the auditory and visual modalities whereas the VA Span hypothesis *a priori* predicts that the simultaneous attention deficit in dyslexic individuals is restricted to the visual modality only (see Fig 3).

The figure below provides a schematic representation of the different predictions of the SAS and VA Span hypotheses regarding visual and auditory processing deficits in developmental dyslexia.
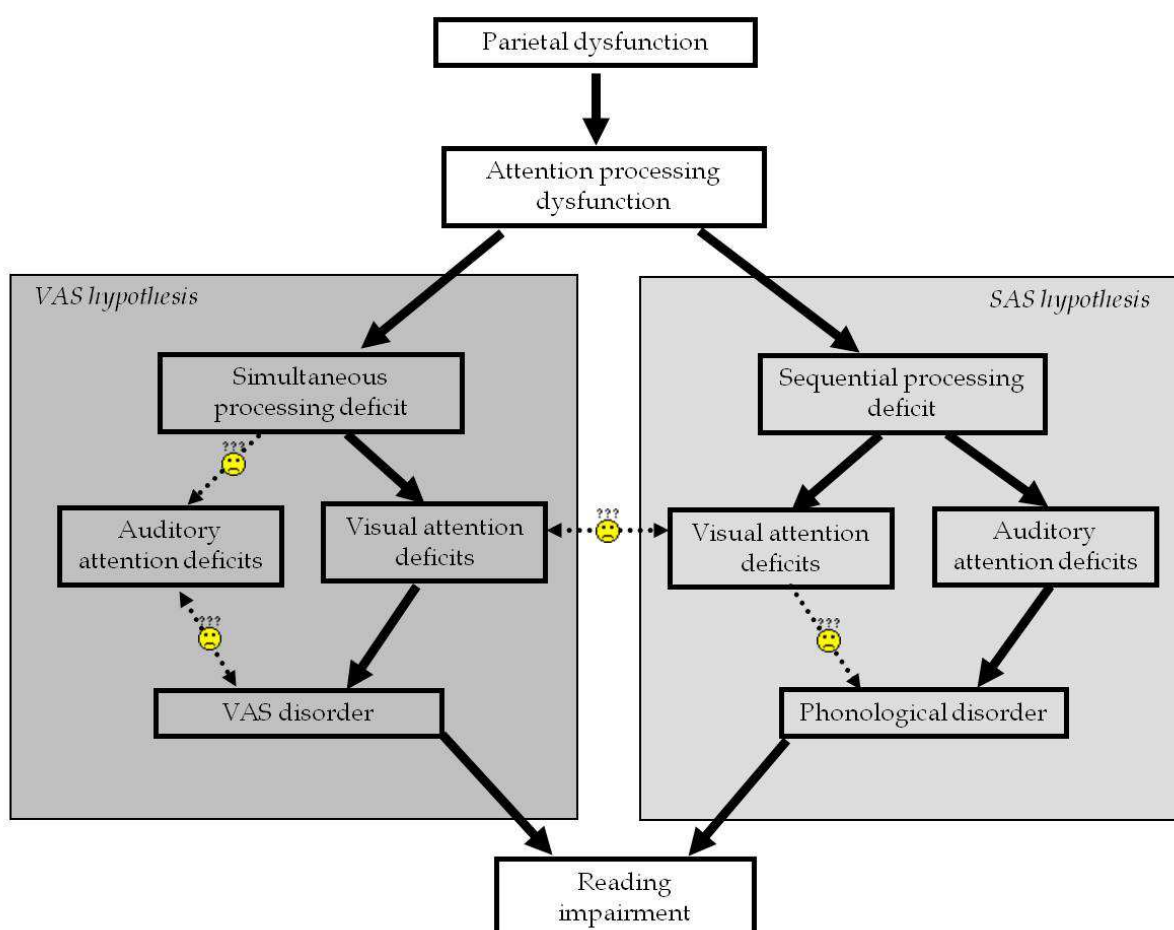
Fig. 3. Schematic representation of the VA Span and SAS hypotheses. The two hypotheses postulate that a parietal dysfunction yields the reading disorder through distinct cognitive impairments (VA Span and phonological disorders respectively). Thick arrows illustrate the causal cascade of impairments leading to developmental dyslexia for each of the two hypotheses. Dotted arrows indicate causal links (simple arrows) or associative links (double arrows) with no or weak support in the literature.

In the following section, we will present arguments in favor of a dissociation between the two hypotheses and between the expected attention impairments. The data that will be presented will address two main questions:

1. The question of amodality will be first addressed. Indeed, Hari and Renvall (2001) in their initial proposal argued for an amodal SAS in developmental dyslexia. They however reported studies that assessed SAS in either the visual or the auditory modality, but never explored the two modalities in the same dyslexic participants, therefore questioning the amodality of the sequential deficits. We will examine to what extent sequential and simultaneous attention deficits quantified on similar paradigms in both the auditory and the visual modalities can be observed in the same dyslexic participants.
2. The second question that we will address is to what extent sequential and simultaneous deficits relate respectively to the phonological and VA Span disorder in developmental dyslexia. In particular, the link between SAS and phonological disorders was never directly assessed in the previously mentioned studies, thus questioning the validity of the causal link between SAS skills and phonological deficits in dyslexia.

Based on experimental evidence, we will argue that sequential and simultaneous attention deficits may play independent roles in the reading disorder, in hindering the development of independent cognitive components which are both required for normal reading acquisition.

2.1 Amodal sequential and simultaneous processing deficits

2.1.1 Sequential processing deficits

Few studies straightforwardly addressed the question of amodal *attentional* processing deficits in dyslexia, since research interests have largely focused on the amodal *perceptual* deficit hypothesis. Disorders extending over several modalities, as expected by the SAS hypothesis, have then been reported (Meyler & Breznitz, 2005). However, a fair amount of data failed to highlight amodal rapid sequential processing disorders in dyslexic individuals, either because of the absence of deficit in the visual modality (e.g., Eddins & Green, 1995; Laasonen et al., 2001; Reed, 1989; Welch, DuttonHurt, & Warren, 1986) or because of the absence of deficits in both modalities (e.g., Bretherton & Holmes, 2003; Laasonen et al., 2000).

Such inconclusive results in the visual modality (as opposed to the auditory modality) could reflect the absence of causal role of visual sequential deficits in developmental dyslexia (see Skottun, 2000). They could also follow from the heterogeneity of the dyslexic population and lack of characterization of the cognitive deficits underlying the reading disorder of dyslexic participants at the individual level. Indeed, knowing that all cases of developmental dyslexia *are not* associated with phonological disorders (Bosse et al., 2007), performance may have been influenced by the heterogeneity of the phonological disorders in the dyslexic sample. In line with this hypothesis, Meyler and Breznitz (2005) who reported a phonological deficit in their dyslexic group did find an amodal sequential deficit in their dyslexic participants.

Differences in the choice of experimental paradigms could also have led to inconsistent results in the observation of amodal sequential deficits in dyslexia. In the original proposal of Tallal (1980), rapid temporal deficits were assessed with order or similarity judgment tasks composed of two stimuli only. Interestingly, the SAS hypothesis predicts deficits on

sequences of multiple (i.e., more than two) stimuli as used in paradigms of stream segregation (Helenius et al., 1999) or attentional blink (Hari et al., 1999). These paradigms seem more appropriate to capture the nature of the auditory and visual processes engaged for the encoding of speech streams or orthographic sequences (these paradigms will be described later in this chapter).

Therefore, we propose that an assessment of SAS amodal deficit in dyslexic participants should be conducted 1) with tasks requiring the processing of long stimulus sequences (see Meyler & Breznitz, 2005, for a similar proposal) and 2) in groups of participants with developmental dyslexia diagnosed with a phonological deficit.

2.1.2 Simultaneous processing deficits

The role of amodal simultaneous processing in reading development has barely been studied. We are aware of only one study which tried to capture amodal simultaneous processing deficit in dyslexia. Geiger et al. (2008) administered to a group of dyslexic children two similar tasks, one in the visual modality, the other one in the auditory modality. In the visual modality, participants were asked to recognize letter stimuli presented in the center of a screen and ignore the letter stimuli in the periphery. In the auditory modality, they had to recognize auditory lexical stimuli presented via speakers located in front of participants (i.e., centrally) with or without the presence of auditory simultaneous peripheral lexical stimuli. Dyslexic children were found to exhibit difficulties in recognizing the central stimuli presented with external noise in both the auditory and the visual modalities. The authors concluded to a "wider perceptual mode" in the dyslexic children, which in turn may hinder their ability to focus on relevant stimuli and inhibit irrelevant information. Unfortunately, this study did not specify whether the assessed dyslexic children exhibited a phonological deficit, making impossible to determine whether such simultaneous processing deficits were found regardless of phonological deficits, as the VA Span hypothesis would predict.

2.2 Assessing visual and auditory sequential and simultaneous deficits in relation to phonological and VA Span disorders in developmental dyslexia

In the following section, we will present evidence that sequential and simultaneous disorders in developmental dyslexia can be found in the same dyslexic participants in both the visual and the auditory modalities. Moreover, we will argue that:

1. sequential and simultaneous automatic attention processes rely on different mechanisms;
2. these mechanisms relate to potentially independent literacy-related cognitive abilities, i.e., phonological (sequential) or VA Span (simultaneous), leading to different dyslexia subtypes.

We first need to emphasize the fact that when investigating auditory and visual non-verbal attention or perception abilities, the underlying cognitive deficits of the dyslexic group should be precisely defined. This is critical in order to investigate the extent to which deficits in non-verbal abilities are linked and result to specific cognitive dyslexic symptoms (i.e., phonological or VA Span disorders). Disregarding this first step may lead to highly

heterogeneous performance in the dyslexic group, hence inconsistent observations between studies.

So far, most of the studies aiming to assess sequential deficits in individuals with developmental dyslexia implicitly assumed that the dyslexic participants exhibited a phonological deficit. Furthermore, other studies which explicitly reported a phonological processing deficit based their diagnosis upon pseudoword reading difficulties (i.e., decoding or sub-lexical reading difficulties), but pseudoword reading does not only require phonological abilities but also engages visual attention (Bosse et al., 2007; Bosse & Valdois, 2009; Facoetti et al., 2006; Facoetti et al., 2010; Vidyasagar & Pammer, 2010).

A number of case studies have now been reported (Dubois et al., 2010; Peyrin, Lallier, Baciu, Démonet, Le Bas, & Valdois, In press; Valdois et al., 2003; Valdois et al., In press) showing that dyslexic individuals (adults or children) with a single VA Span deficit may suffer from poor pseudoword reading abilities (reading accuracy and/or reading speed) *in spite of* any difficulties in "pure auditory" phonological processing skills.

From these considerations, it appears critical to systematically base the diagnosis of phonological disorders in dyslexic patients on measures of auditory phonological processing rather than on decoding skills. This precaution alone can ensure avoiding the impact of visual attention on performance, which would no longer reflect the "phonological disorder" primarily targeted.

We therefore will present data from a series of studies suggesting that sequential attention skills preferentially relate to phonological (and not decoding) skills rather than VA Span skills. We chose two experimental paradigms - the attentional blink and the stream segregation paradigms - that we thought had a great sensitivity to capture the rapid sequential processing abilities required for reading acquisition development (presentation of multiple stimuli in rapid sequences). These two tasks are supposed to allow the evaluation of temporal automatic attention deployment via attentional shifting, i.e., the successive engagement and disengagement of the attentional focus over a sequence of multiple stimuli.

2.2.1 Amodal sequential processing assessment: The attentional blink

Hari and Renvall (2001) predict that a prolongation of the attentional dwell time (see section 1.1.3 for a definition) in all sensory modalities would result in developmental dyslexia. The attentional dwell time has been highlighted in rapid serial presentation paradigms (10 items/sec) requiring the identification and/or detection of two targets (T1 and T2) embedded in a series of distracters. When the two targets are present in the sequence, performance on T1 is high whereas performance on T2 is lower. This drop of T2 performance (also called the attentional blink) is all the more interesting that it varies according to its temporal position as regards the presentation of T1 (Raymond et al., 1992).

In attentional blink tasks, two conditions are generally used: a dual task condition (see white dots in Fig 4.a.) where participants have to identify T1 and detect the presence or absence of T2, and a single task condition (see black squares in Fig 4.a.) which serves as a baseline, and where T1 is absent and only T2 has to be detected. Results on this task show an attentional blink, which is typically observed during a temporal window of about 300-500 ms after T1 presentation. In order to characterize the attentional blink more accurately, Cousineau,

Charbonneau, and Jolicoeur (2006) measured the phenomenon according to four parameters defining a curve fitting function (see Fig 4.b.): the duration parameter corresponds to the duration of the attentional blink, the amplitude parameter corresponds to the difference between the best and the worst performance and indicates the severity of the attentional blink, the minimum parameter corresponds to the worst performance, and lag-1 sparing parameter corresponds to the speed at which T1 processing starts to have a negative impact on T2 processing. The SAS hypothesis predicts a longer attentional blink duration in dyslexic participants with phonological disorders.
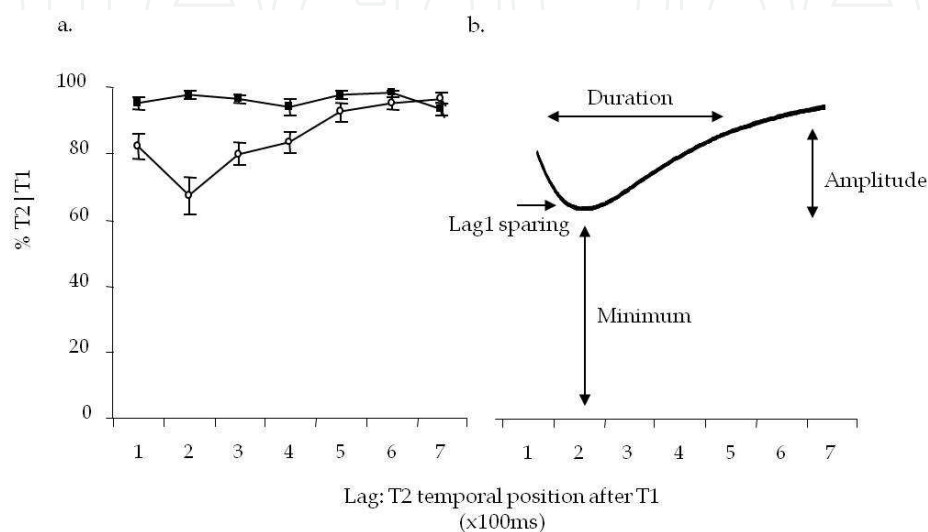
Fig. 4. Representation of the typical pattern of performance obtained in attentional blink (a). When compared to the single task condition (black squares), performance on the dual task condition (white dots) drops for the first four positions of T2 after T1. The four attentional blink parameters adapted from Cousineau et al. (2006) are presented in (b).

Several studies have shown that dyslexic individuals exhibit a prolonged visual attentional blink (lasting in average 600-800 ms) as compared to normal readers (e.g., Hari, Valta, and Uutela, 1999b; Visser, Boden, & Giaschi, 2004; Facoetti, Ruffino, Peru, Paganoni, & Chelazzi, 2008). This finding suggests that T1 captures visual attention resources for longer time in dyslexic participants than in control participants. However, research conducted on the attentional blink in impaired readers has given rise to discrepant results and has been subject to criticisms (Badcock, Hogben, & Fletcher, 2008).

Overall, previous studies conducted in dyslexic participants suffer from a lack of homogeneity regarding either the characterization of the cognitive deficit underlying dyslexia (i.e., phonological or VA Span disorder), or methodological aspects. Furthermore, although the attentional blink had been highlighted in the auditory modality (e.g., Vachon & Tremblay, 2008), no study had examined whether dyslexic participants presented an atypical attentional blink in this modality as in vision.

In a first study (Lallier, Donnadieu, Berger, & Valdois, 2010a), we assessed the amodality assumption of the SAS hypothesis by administering two similar attentional blink tasks in the visual and the auditory modalities to a French dyslexic adult participant, LL, and a group of skilled reader adults. The neuropsychological assessment of LL revealed that this patient suffered from a phonological dyslexia as characterised by slowed pseudoword reading rate

and poor pseudoword spelling. LL further had poor pseudoword repetition and poor phoneme awareness skills, thus reflecting an underlying phonological disorder. On the contrary, LL showed normal simultaneous processing of letter strings on the whole and partial report tasks, thus suggesting preserved VA Span abilities.

The visual attentional blink task consisted in the rapid serial presentation of black digits. T1 was the only red digit in the stream and it was either 1 or 5. T2 was the digit 0 and was black like the distracters. The auditory attention blink task consisted in the rapid serial auditory presentation of sounds. Pure tones were used as distracters and a higher-pitched tone of 4000 Hz was used as T1 target. This tone was either a complex tone (sounding like a locust cry) or pure tone (sounding like a bird cry), giving rise to two distinct perceptions. T2 was a pure tone of 600 Hz belonging to the distracters' frequency range but it was delivered at a higher amplitude level (i.e., it was louder). In the dual task condition, participants were instructed to attend to and name T1 (1 or 5 digits; pure or complex tones) while judging whether T2 occurred or not (number 0; louder sound). For both the single and dual task conditions, we took into account eight T1-T2 lags in the analyses, i.e., from lag 1 (no intervening items, ISI = 60 ms) to lag 8 (ISI = 760 ms). For each of the visual and the auditory tasks, participants were instructed to name T1 and/or report aloud whether T2 was present or not, after each sequence was seen or heard.
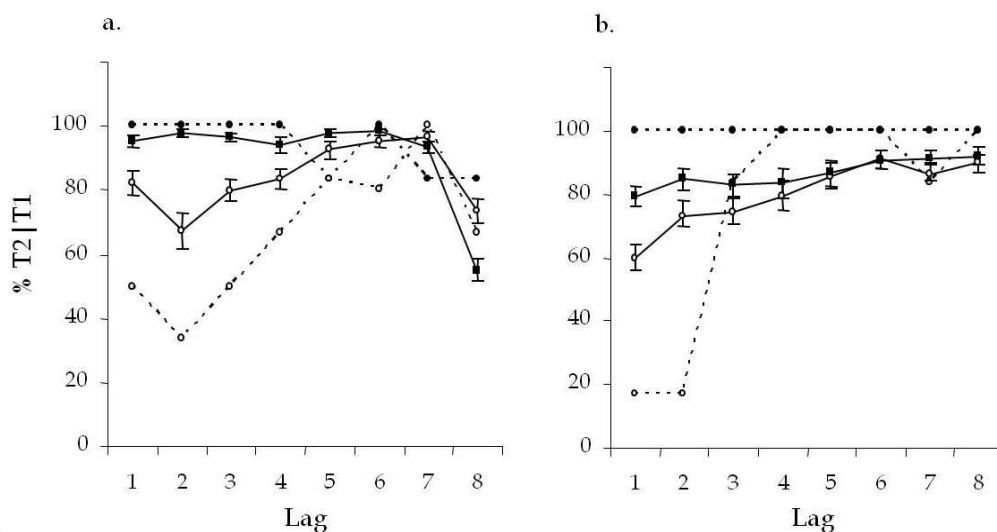

Fig. 5. Visual (a.) and auditory (b.) attentional blinks in the control group (plain lines) and in LL (dotted lines) for the single task condition (black dots) and for the dual task condition (white dots). From Lallier et al., 2010a.

When LL's performance was compared to performance of skilled readers, it revealed atypical visual attentional blink duration and atypical auditory attentional blink amplitude (see Fig 5). Both atypical attentional blinks were interpreted as reflecting prolonged attentional dwell time, thus demonstrating amodal SAS skills in LL. Interestingly, this amodal disorder was reported in a dyslexic participant with a phonological disorder, in accordance with the SAS hypothesis. Moreover, the auditory and visual attentional blink deficits were found independently of any VA Span disorder, suggesting that sequential and simultaneous attention processing could dissociate and might independently contribute to developmental dyslexia.

In a second study (Lallier, Donnadieu, & Valdois, 2010b), we used the curve fitting method of Cousineau et al. (2006) to quantify and better define the visual attentional blink deficit of dyslexic children. We further explored whether any parameter specifically related to their phonological disorder (Lallier et al., 2010b). Fourteen dyslexic children and 14 age-matched control children took part in the experiment. The dyslexic group was impaired in phonological short-term memory and showed marginally poor phoneme deletion skills but performed as well as the controls on the partial or whole report task, thus suggesting preserved VA Span skills (Lallier, 2009). All children were given the same visual attentional blink task as in Lallier et al (2010a). A group effect was revealed on the attentional blink minimum parameters, reflecting a lower minimum for the dyslexic group than the control group, but no difference regarding duration of the attentional blink. Correlation analyses on the whole sample revealed that the attentional blink minimum and amplitude parameters significantly correlated, and that attentional blink amplitude was significantly related to phonemic deletion skills.

From these findings and previous other results, it seems that deficits in several attentional blink features (see Fig 4) could occur in the same dyslexic participants. Indeed, both atypical attentional blink "duration *and* minimum" (Facoetti et al., 2008; Hari et al., 1999) and "duration *and* amplitude" (Lallier et al., 2010a) have been reported in the same participants. Such result is *a priori* not surprising given the correlation reported between all three parameters (Cousineau et al., 2006).

To sum up, our two studies assessing sequential attention processing with attentional blink tasks in dyslexic participants showed that a visual sequential attention deficit can be found in the absence of any visual simultaneous attention disorder. Moreover, both auditory and visual SAS skills were preferentially associated with phonological deficits in developmental dyslexia.

2.2.2 Amodal sequential processing assessment: Stream segregation

In another series of studies we will present in this section, we used the experimental paradigm used for the assessment of stream segregation. Interestingly, stream segregation can be observed in the two modalities. In the auditory modality (Bey & McAdams, 2003), stream segregation occurs when sequences of auditory stimuli alternate in pitch/auditory frequency (e.g. high and low pitch tones). In the visual modality (Bregman & Achim, 1973), segregation occurs when sequences of visual stimuli alternate in spatial locations (e.g. visual dots appearing above and below fixation). The resulting percept depends on both temporal and auditory frequency/visual distance intervals between two successive stimuli (Van Noorden, 1975).

For adequate auditory frequency/visual distance intervals, two perceptual temporal patterns can occur (see Fig 6):

i.   When time interval is long enough, a unique auditory stream alternating high and low pitch tones (or a unique visual object composed of two dots bouncing up and down) is perceived.
ii.   For short enough intervals, the participants perceive two different auditory streams, one high- and the other low-pitched (or two visual dots flickering in parallel).

Focusing on the temporal aspects of the phenomenon, auditory stream segregation has been assessed in dyslexia, showing that dyslexic individuals required longer ISIs to perceive the

one unique auditory stream (i.e., the alternation of two distinct sounds) as compared to skilled readers. Hari and Renvall (2001) interpreted this result as evidence for auditory SAS skills in individuals with developmental dyslexia.

In the following series of experiments, we used the paradigms of Helenius et al. (1999) in the auditory modality, and designed a similar paradigm to assess stream segregation skills in the visual modality. For both tasks, we measured stream segregation thresholds according to an adaptive procedure that allows varying the ISI between the successive stimuli in the sequences according to the answer/perception of participants ("one stream", cf Fig 6.a., or "two streams", cf Fig 6.b.).

a.   b.
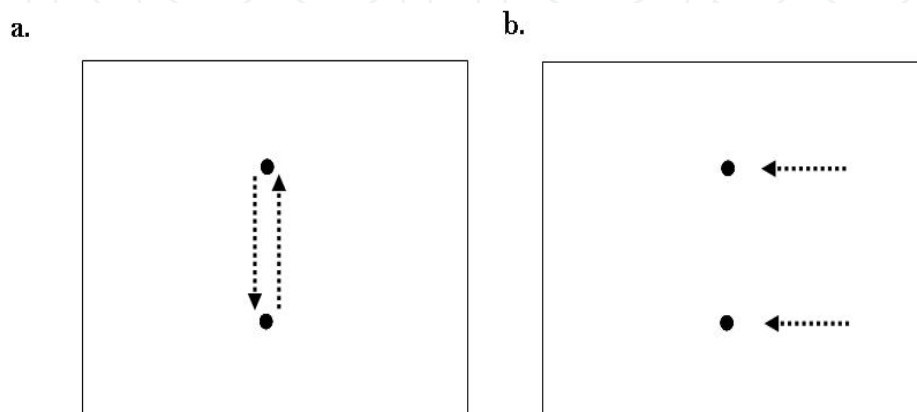
Fig. 6. Schematic representation of the stream segregation procedure. The dotted arrows symbolise the one stream (a., longer ISIs) or two streams (b., shorter ISIs) conditions. From Lallier et al. 2010c.

Stream segregation thresholds correspond to the ISI for which participants cannot straightforwardly decide if they perceive one stream or two streams of stimuli, corresponding to a response "at chance".

We interpreted stream segregation thresholds as an estimation of the fastest speed at which attention could engage and disengage automatically from one stimulus to another in order to perceive them as independent entities.

The first study (Lallier et al., 2009) combined two experiments: one with children, one with adults. In the first experiment, we tested 36 children on both the visual and the auditory stream segregation tasks. Twelve children were diagnosed as dyslexic and, as a group, showed a phonological impairment (phoneme deletion and phonological short term memory) together with a mild VA Span disorder illustrated by a deficit on the whole report task but not on the partial report task (Lallier, 2009). The other participants were either skilled readers (12 children) or poor readers (12 children). The three groups of children were matched for chronological age but significantly differed between each other on their reading skills.

Results on the segregation tasks showed that dyslexic children exhibited higher auditory thresholds than the two other groups of non dyslexic readers, suggesting SAS skills in the dyslexic group as compared to the non dyslexic groups (see Fig 7.a., top graph). Furthermore, poor readers exhibited a higher auditory threshold than skilled readers. Such

results suggest a strong link between reading skills and auditory stream segregation thresholds and consequently, between reading skills and auditory automatic attention shifting, which was also supported by correlation analyses. In the visual modality no difference was reported between any of the groups (see Fig 7.a., bottom graph).
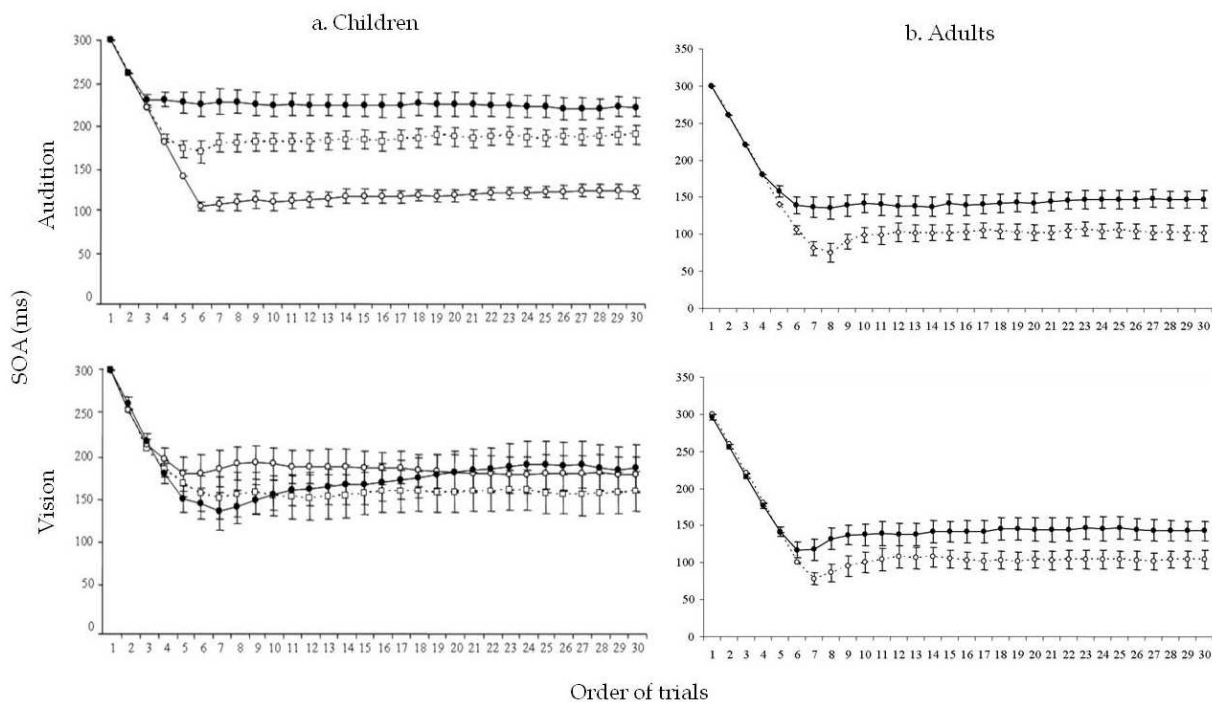

Fig. 7. Mean auditory and visual stream segregation thresholds (average ISI on the last 10 trials) together with standard error bars in children (a.; dyslexic readers, black dots; poor readers, white squares; good readers, white dots) and adults (b.; dyslexic readers, black dots; skilled readers, white dots). Adapted from Lallier et al. 2009.

The second experiment (see Fig 7.b) was carried out with 10 skilled readers and 10 dyslexic young adults. As a whole, the dyslexic group showed difficulties in performing a spoonerism task, reflecting poor phonological awareness skills. Furthermore, the group presented a VA Span disorder as compared to controls, illustrated by difficulties on both the whole and the partial report tasks (Lallier, 2009). Results on the two stream segregation tasks showed that dyslexic adults obtained auditory and visual higher stream segregation thresholds as compared to the control group: this means that they needed more time than the control individuals between successive stimuli, i.e., longer ISIs, in order to perceive them as single entities. The results on both the visual and the auditory task thus reflected amodal SAS skills in the dyslexic group. In addition, significant relationships were found in the whole group of participants (dyslexic and control individuals) between SAS, poor reading and poor phonological skills, even after controlling for non-verbal IQ and chronological age. No such relation was found between VA Span skills and visual or auditory stream segregation thresholds (Lallier, 2009).

Overall, the results of the two experiments of Lallier et al. (2009) with children and adults support the view that auditory SAS impacts on phonological abilities, and plays a role in developmental dyslexia. In addition, the comparison between children and adult results

suggests that a visual sequential disorder in dyslexia might emerge at a later developmental stage, when the visual system normally becomes more expert at rapid temporal processing.

In the second study (Lallier et al., 2010c), we quantified both auditory and visual stream segregation thresholds in 13 dyslexic young adults with a phonological awareness deficit as a group (poor performance on phonemic deletion and spoonerisms) and 13 control participants, matched for cognitive abilities. Consistent with Lallier et al. (2009), we found higher auditory and visual stream segregation thresholds in the dyslexic group as compared to the controls, thus evidence for amodal SAS skills. We then used electrophysiological measures allowing us to capture the electric activity produced naturally by the brain, to determine to what extent brain responses of these dyslexic participants would reflect their atypical perception of visual and auditory stimulus sequences. For the electrophysiological experiment, the auditory and visual sequences administered to the participants varied according to different tempos that were carefully chosen based on preliminarily obtained thresholds. Participants were presented with blocks of 4 min-long sequences of either the same auditory or the same visual stimuli as those used in the stream segregation tasks, whilst their brain responses were recorded by electroencephalography (i.e., EEG). They were asked to press a button as soon as they perceived a change in the speed of stimulus alternation, and were not told or asked anything about the perception of unique or distinct streams. Electrophysiological brain responses were recorded during the task, and interpreted as an index of stimulus sequence perception. Results showed that dyslexic participants presented atypical auditory and visual brain responses to tempos variations within stimulus sequences as compared to controls.

Overall, these results strongly support the hypothesis that SAS in dyslexic participants might be responsible for their atypical perception of rapid sequential stimulus sequences in both the auditory and the visual modalities. In the auditory modality, the atypical brain response elicited by rapid stimulus sequences is likely to index the atypical perception of auditory speech streams in dyslexic participants with a phonological disorder. In the visual modality, such abnormal rapid stimulus sequences perception could well relate to difficulties encountered by dyslexic participants in rapidly shifting their attention along the orthographic sequences composing texts (Hari & Renvall, 2001). The direct links between stream segregation tasks and speech and orthographic strings processing still need to be investigated. Furthermore, our results bring new evidence supporting the link between amodal SAS and the phonological impairment in developmental dyslexia.

In our previous studies evaluating attentional blink or stream segregation performance in dyslexic individuals, links between sequential attention deficits and the phonological and VA Span disorders were studied by means of correlation analyses carried out on the whole sample of participants (i.e., including both dyslexic and skilled readers), a choice that may raise some methodological concerns. Furthermore, phonological and VA Span disorders were always defined regarding the whole group of dyslexic participants (except for Lallier et al., 2010a).

The next study conducted in adults (Lallier, Thierry, & Tainturier, Under Review b; Lallier, Thierry, Valdois & Tainturier, In progress b) was conducted in order to ascertain the relationships between amodal SAS skills and both phonological and VA Span disorders in a more stringent way. We examined performance of three groups of participants on the

stream segregation tasks. These three groups included (i) a group of nine skilled reader adults, (ii) a group of nine dyslexic adults each of whom exhibited a phonological deficit at the individual level (i.e., impaired on three phonological measures out of five, among phonological working memory, phonological fluency, phonemic deletion, and spoonerism time and accuracy), and (iii) nine dyslexic adults without any phonological deficit. Regarding visual attention performance, the two dyslexic groups showed a significant VA Span deficit on the whole report task as compared to the controls. On the partial report task, the three groups of participants showed similar scores (Lallier et al., In progress b). Importantly, the three groups were matched for non-verbal IQ and chronological age, and the two dyslexic groups were matched for general reading and spelling abilities. Therefore, we were in presence of a relatively pure phonological dyslexic group, and a non-phonological dyslexic group with a VA Span disorder. In line with the hypothesis of a dissociation between phonological *versus* VA Span disorder and sequential *versus* simultaneous attention deficits in developmental dyslexia, only the dyslexic group with a phonological disorder exhibited higher auditory and marginally higher visual stream segregation thresholds as compared to the control group (see Fig 8).
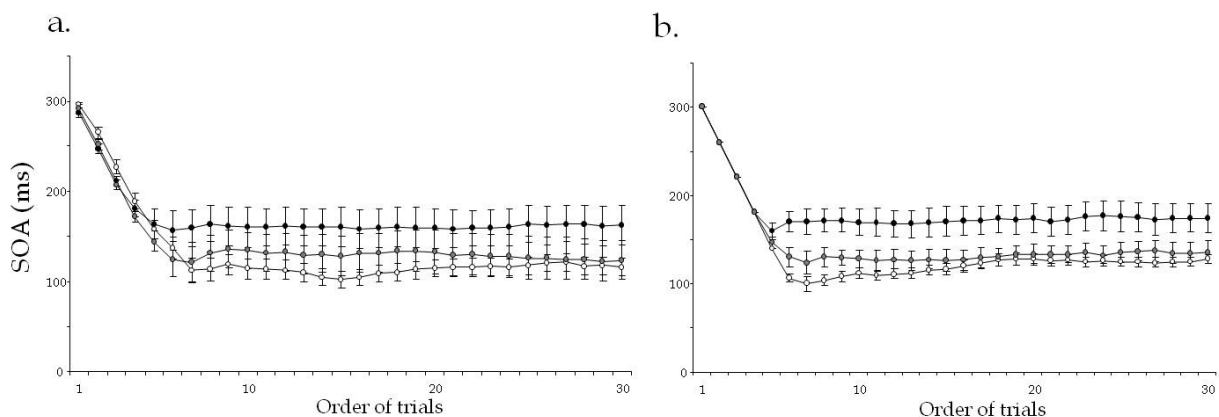
Fig. 8. Visual (a.) and auditory (b.) stream segregation thresholds together with standard error bars in the dyslexic group with a phonological disorder (black dots), the dyslexic group without phonological disorder (grey dots) and the control group (white dots). Adapted from Lallier et al., Under Review b, and Lallier et al., In progress b.

Importantly, auditory thresholds significantly differed between the two dyslexic groups. Looking at individual performance, 78% of participants with a phonological disorder (*versus* 11% without) were impaired on the auditory stream segregation task and 33% (*versus* 11%) on the visual task. These results strongly support the hypothesis of a link between auditory (and visual, but to a lesser extent) sequential deficits, impaired phonology, and reading disorders, but do not suggest any link between VA Span disorder and auditory or visual SAS in developmental dyslexia.

2.2.3 Amodal simultaneous processing assessment: Dichotic listening

In order to obtain a complete picture of the contribution of sequential and simultaneous skills to reading difficulties in the dyslexic population regarding auditory processing, we designed a task that we considered to be a reasonable auditory counterpart of the visual whole report task (Lallier, Donnadieu, & Valdois, Under Review a). That way, we aimed to

assess the amodality of simultaneous attention in dyslexic children. We chose a dichotic listening paradigm (Cherry, 1953) which has broadly been used to assess simultaneous auditory attention (e.g., Asbjörnsen & Hugdahl, 1995). In dichotic tasks, different auditory sources of information are simultaneously displayed in the two ears. As opposed to the *focal* attention condition where participants have to report the stimuli presented in one ear only, the *non focal* attention reflect the performance of participants when they have to report the stimuli presented in the two ears. The latter condition makes the participants allocate their attention resources in parallel to the two ears and indexes some attention resources limitation. We measured the report scores of participants in the latter condition in order to quantify their simultaneous auditory attention abilities.
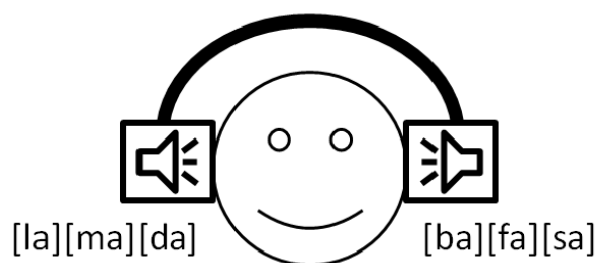
Fig. 9. Illustration of the dichotic listening task we used to assess simultaneous attention resources. From Lallier et al., Under Review a.

The dichotic sequences were composed of three syllables sequentially presented in the right ear and of three different syllables sequentially presented in the left ear (see Fig 9). More importantly, the two series of syllables were carefully synchronized so that participants had to process pairs of syllables simultaneously presented in the two ears. They were instructed to listen carefully to the syllables presented in their right ear and in their left ear and to report as many syllables as possible from both sides.

Because auditory syllables were used as stimuli, relations between dichotic performance and phonological processes were likely to be shown. We therefore assessed VA Span abilities, phoneme awareness skills and phonological short-term memory in dyslexic children together with their dichotic listening performance. We reasoned that if phonological and VA Span skills play different roles in reading acquisition and are respectively associated with sequential and simultaneous processes (Lallier et al., 2010a), performance on a task requiring a high degree of simultaneous resource allocation should fail to, or only weakly, relate to phonological skills, even when participants are presented with phonological stimuli. However, if poor dichotic listening performance is mainly driven by simultaneous processing difficulties and if the simultaneous processing disorder is amodal, then dyslexic children with a VA Span disorder should perform poorly on the dichotic listening task *whether or not* they exhibit associated phonological deficits. On the other hand, if dichotic listening poor performance is determined by difficulties in phonological/sequential processing abilities, then individuals with phonological deficits should perform poorly on the dichotic listening task regardless of their VA Span skills.

We assessed the dichotic listening performance of 17 dyslexic children and 17 skilled readers. Results showed that the dyslexic group exhibited difficulties in reporting the simultaneous syllables as compared to the controls. Moreover, in the dyslexic group, VA

Span skills correlated positively with dichotic listening scores while phonological skills did not correlate with either dichotic or VA Span measures. All the dyslexic children with a dichotic listening deficit showed a VA Span disorder, but the VA Span disorder was not systematically associated with poor dichotic listening. A high proportion of dyslexic children exhibited a phonological short-term memory or a phonemic awareness deficit whether or not they had difficulties on the dichotic listening task. Our findings suggest that processing simultaneous auditory stimuli in developmental dyslexia may be impaired regardless of any phonological deficit and be linked to similar difficulties in the visual modality.

3. Conclusion

This chapter aimed to clarify the nature of the temporal dimension of processing (sequential or simultaneous) relevant for the study of visual and auditory deficits (verbal or non-verbal) in developmental dyslexia. First, our review of the available data suggests that processes tapping into automatic attention mechanisms may be likely to highlight critical links between auditory and visual deficits and reading disorders. Second, our series of experiments provides new evidence for a potential dissociation between sequential and simultaneous processing deficits in developmental dyslexia and their respective links to distinct cognitive dyslexic profiles (VA Span and phonological disorders): when auditory automatic attentional shifting speed seems to clearly contribute to phonological processing (phonological awareness and phonological short-term memory in particular), the link between similar visual measures and reading is weaker, as previously suggested in the literature (e.g., Skottun, 2000). Our data further suggests that visual simultaneous disorders could extend over the auditory modality in participants with dyslexia regardless of their phonological skills.

3.1 The role of sequential *versus* simultaneous amodal attention processing in reading

When looking at what reading is, it seems obvious that both the auditory and visual perceptual-attentional systems have an important role to play. In their theoretical account integrating auditory and visual networks together with their role in developmental dyslexia, Pammer and Vidyasagar (2005) suggest that automatic spatial attentional orientation and focalization are the amodal mechanisms playing a fundamental role in reading acquisition. In the visual modality, such mechanisms would be in charge of screening and encoding at a pre-orthographic level the visual letter strings, such as coding letter positions within the string (e.g., Pammer, Lavis, Hansen, & Cornelissen, 2004), in order to facilitate grapheme-to-phoneme conversion rules acquisition. In the auditory modality, similar attentional mechanisms would be required to encode speech units to form adequate phonological representations (Hari & Renvall, 2001).

In the present chapter, we proposed that auditory and visual mechanisms engaged in reading acquisition require both sequential and simultaneous processes to encode phonological and orthographic inputs. The first one, a sequential attention mechanism, would lead the attentional focus to rapidly and automatically engage and disengage over speech streams and orthographic sequences, whilst being guided by salient and relevant cues (syllabic stress, Goswami, 2011; or visual syllable, Ans et al., 1998). The second one

would be a simultaneous attention mechanism: because in real life situations the attended auditory and visual inputs very rarely correspond to one single small unit (such as a letter isolated on a blank page or a single phoneme presented in a quiet environment), simultaneous processing resources are required in order to integrate (VA Span hypothesis) or inhibit (noise exclusion deficit hypothesis, Sperling, Manis, & Seidenberg, 2005) all pieces of information presented at the same time (e.g., multi-letter strings or multi-speaker environments). Future studies will seek to determine to what extent these two mechanisms in charge of processing multiple inputs presented simultaneously (i.e., integrating *versus* filtering/inhibiting) contribute to literacy acquisition, and possibly independently of each other.

3.2 The hypothesis of different independent time scales auditory and visual processing and reading development?

Poeppel (2003) suggested that two types of time scales for auditory processing are relevant and important for language acquisition: one would be handled by a very high oscillatory auditory system, whereas the other would be linked to a low oscillatory auditory system. Interestingly, the latter could possibly relate to sequential processing, whereas the former could be more tightly related to the "simultaneous" dimension of processing which would in this case correspond to a sequential processing at very high rate. Future studies will aim to clarify whether these two time scales of processing could extend over the visual domain, and to what extent they would impact on reading acquisition. Moreover, it will be necessary to examine whether these two time scales of processing have different and possibly independent roles in literacy acquisition, and lead to different subtypes of developmental dyslexia.

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5. References

Asbjornsen, A. E., & Hugdahl, K. (1995). Attentional Effects in Dichotic Listening. *Brain & Language,* Vol.49, No.3, (June 1995), pp. 189-201, **ISSN** 0093-934X.

Amitay, S., Ben-Yehudah, G., Banai, K., & Ahissar, M. (2002). Disabled readers suffer from visual and auditory impairments but not from a specific magnocellular deficit. *Brain,* Vol.125, No.10, (October 2002), pp. 2272-2285, ISSN 1460-2156.

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multiple-trace memory model for polysyllabic word reading. *Psychological Review,* Vol.105, No.4, (October 1998), pp. 678-723, ISSN 0033-295X.

Au, A., & Lovegrove, B. (2001a). The role of visual and auditory temporal processing in reading irregular and nonsense words. *Perception,* Vol.30, pp. 1127-1142, ISSN 1468-4233.

Au, A., & Lovegrove, B. (2001b). Temporal processing ability in above average and average readers *Perception & Psychophysics,* Vol.63, No.1, pp. 48-55, ISSN 0031-5117.

Badcock, N. A., Hogben, J. H., & Fletcher, J. F. (2008). No differential attentional blink in dyslexia after controlling for baseline sensitivity. *Vision Research,* Vol.48, No.13, pp. 1497-1502, ISSN 0042-6989.

Bailey, P. J., & Snowling, M. J. (2002). Auditory processing and the development of language and literacy. *British Medical Bulletin,* Vol.63, pp. 135-146, ISSN 1471-8391.

Ben-Yehudah, G., Sackett, E., Malchi-Ginzberg, L., & Ahissar, M. (2001). Impaired temporal contrast sensitivity in dyslexics is specific to retain-and-compare paradigms. *Brain,* Vol.124, No.7, pp. 1381-1395, ISSN 1460-2156.

Benasich, A. A., & Tallal, P. (1996). Auditory temporal processing thresholds, habituation, and recognition memory over the 1st year. *Infant Behavior and Development,* Vol.19, No.3, pp. 339-357, ISSN 0163-6383.

Benasich, A. A., & Tallal, P. (2002). Infant discrimination of rapid auditory cues predicts later language impairment. *Behavioural Brain Research,* Vol.136, No.1, pp. 31-49, ISSN 0166-4328.

Bey, C., & McAdams, S. (2002). Schema-based processing in auditory scene analysis. *Perception & Psychophysics,* Vol.64, No.5, pp. 844-854 , SSN 0031-5117.

Boden, C., & Giaschi, D. (2007). M-stream deficits and reading-related visual processes in developmental dyslexia. *Psychological bulletin,* Vol.133, No.2, pp. 346-366, *I*SSN 0033-2909.

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: the visual attention span deficit hypothesis. *Cognition,* Vol.104, No.2, pp. 198-230, ISSN 0010-0277.

Bosse, M. L., & Valdois, S. (2009). Influence of the visual attention span on child reading performance: a cross-sectional study. *Journal of Research in Reading*, Vol.32, pp. 230–253, ISSN 1467-9817.

Bretherton, L., & Holmes, V. M. (2003). The relationship between auditory temporal processing, phonemic awareness, and reading disability. *Journal of Experimental Child Psychology,* Vol.84, No.3, pp. 218-243, ISSN 0022-0965.

Bregman, A. S., & Achim, A. (1973). Visual stream segregation. *Perception & Psychophysics,* Vol.13, No.3, pp. 451-454, ISSN 0031-5117.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awarness to sucess in learning to read? *Cognition,* Vol.91, pp. 77-111, **ISSN** 0010-0277.

Cestnick, L., & Coltheart, M. (1999). The relationship between language-processing and visual-processing deficits in developmental dyslexia. *Cognition,* Vol.71, No.3, pp. 231-255, **ISSN** 0010-0277.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and two ears. *Journal of the Acoustical Society of America,* Vol.25, pp. 975-979, ISSN 0001-4966.

Chiappe, P., Stringer, R., Siegel, L. S., & Stanovich, K. E. (2002). Why the timing deficit hypothesis does not explain reading disabilitiy in adults. *Reading and Writing: An interdisciplinary Journal,* Vol.15, pp. 73-107, ISSN 0922-4777.

Clarke, S., Bellmann, A., Meuli, R. A., Assal, G., & Steck, A. J. (2000). Auditory agnosia and auditory spatial deficits following left hemispheric lesions: evidence for distinct processing pathways. *Neuropsychologia,* Vol.38, No.6, pp. 797-807.

Cornelissen, P., Richardson, A., Mason, A., Fowler, S., & Stein, J. (1995). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research,* Vol.35, No.10, pp. 1483-1494, ISSN 0042-6989.

Cousineau, D., Charbonneau, D., & Jolicoeur, P. (2006). Parameterizing the attentional blink effect. *Canadian Journal of Experimental Psychology,* Vol.60, No.3, pp. 175-189, ISSN 1196-1961.

De Martino, S., Espesser, R., Rey, V., & Habib, M. (2001). The "temporal processing deficit" hypothesis in dyslexia: new experimental evidence. *Brain & Cognition,* Vol.45. No.1-2, pp. 104-108, ISSN 0278-2626.

Dubois, M., Kyllingsbæk, S., Prado, C., Musca, S.C., Peiffer, E., Lassus-Sangosse, D., et al. (2010). Fractionating the multicharacter processing deficit in developmental dyslexia: Evidence from two case studies. *Cortex,* Vol. 46, No.6, pp.717-738, ISSN 0010-9452.

Eddins, D. A., & Green, D. M. (1995). *Temporal integration and temporal resolution*. Academic Press, In M. BCJ (Ed.), Hearin*g.* San Diego, California, U.S.A.

Edwards, V. T., Giaschi, D. E., Dougherty, R. F., Edgell, D., Bjornson, B. H., Lyons, C., et al. (2004). Psychophysical indexes of temporal processing abnormalities in children with developmental dyslexia. *Developmental Neuropsychology,* Vol.25, No.3, pp. 321-354, ISSN 0012-1649.

Ehri, L. C., Nunes, S. R., Willows, D. M., Schuster, B. V., Yaghoub-Zadeh, Z., & Shanahan, T. (2001). Phonemic awareness instruction helps children learn to read : Evidence from the National Reading panel's meta-analysis. *Reading Research Quarterly,* Vol.36, No.3, pp. 250-287, ISSN 1936-2722.

Facoetti, A., Lorusso, M. L., Paganoni, P., Umilta, C., & Mascetti, G. G. (2003). The role of visuospatial attention in developmental dyslexia: evidence from a rehabilitation study. *Brain Research Cognitive Brain Research,* Vol.15, No.2, pp. 154-164, ISSN 1872-6348.

Facoetti, A., & Molteni, M. (2001). The gradient of visual attention in developmental dyslexia. *Neuropsychologia,* Vol.39, No.4, pp. 352-357, ISSN 0028-3932.

Facoetti, A., Paganoni, P., Turatto, M., Marzola, V., & Mascetti, G. G. (2000). Visual-spatial attention in developmental dyslexia. *Cortex,* Vol.36, No.1, pp. 109-123, ISSN 0010-9452.

Facoetti, A., Ruffino, M., Peru, A., Paganoni, P., & Chelazzi, L. (2008). Sluggish engagement and disengagement of non-spatial attention in dyslexic children. *Cortex,* Vol.44, No.9, pp. 1221-1233, ISSN 0010-9452.

Facoetti, A., Trussardi, A. N., Ruffino, M., Lorusso, M. L., Cattaneo, C., Galli, R., Molteni, M., & Zorzi M. (2010). Multisensory Spatial Attention Deficits Are Predictive of Phonological Decoding Skills in Developmental Dyslexia. *Journal of Cognitive Neuroscience*. Vol.22, No.5, pp. 1011-1125, ISSN 1530-8898.

Facoetti, A., & Turatto, M. (2000). Asymmetrical visual fields distribution of attention in dyslexic children: a neuropsychological study. *Neuroscience Letters,* Vol.290, No.3, pp. 216-218, ISSN 0304-3940.

Facoetti, A., Zorzi, M., Cestnick, L., Lorusso, M. L., Molteni, M., Paganoni, P., et al. (2006). The relationship between visuo-spatial attention and nonword reading in developmental dyslexia. *Cognitive Neuropsychology,* Vol.23, No.6, pp. 841-855, ISSN 1464-0627.

Farmer, M. E., & Klein, M. R. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin & Review,* Vol.2, No.4, pp. 460-493, ISSN 1531-5320.

Friedmann N, & Nachman-Katz, I. (2004) Developmental neglect dyslexia in a Hebrew-reading child. *Cortex*, Vol.40, pp. 301-313, ISSN 0010-9452.

Friedmann, N. & Rahamim, E. (2007) Developmental letter position dyslexia. *Journal of Neuropsychology*, Vol.1, pp. 201- 236, ISSN 1748-6653.

Galaburda, A. M., Menard, M. T., & Rosen, G. D. (1994). Evidence for aberrant auditory anatomy in developmental dyslexia. *Proceedings of the National Academy of Sciences,* Vol.91, No.17, pp. 8010-8013, ISSN 0027-8424.

Geiger, G., Cattaneo, C., Galli, R., Pozzoli, U., Lorusso, M. L., Facoetti. A., and Molteni M. (2008) Wide and diffuse perceptual modes characterize dyslexics in vision and audition. *Perception*. Vol.37, No.11, pp. 1745-64, ISSN 1468-4233.

Goswami, U., (2011). A temporal sampling framework for developmental dyslexia. *Trends in Cognitive Sciences*, Vol.15, No.1, pp.3–10, ISSN 1364-6613.

Habib, M., Rey, V., Daffaure, V., Camps, R., Espesser, R., Joly-Pottuz, B., et al. (2002). Phonological training in children with dyslexia using temporally modified speech: a three-step pilot investigation. *International Journal of Language & Communication Disorders,* Vol.37, No.3, pp. 289-308, ISSN 1460-6984.

Hairston, W. D., Burdette, J. H., Flowers, D. L., Wood, F. B., & Wallace, M. T. (2005). Altered temporal profile of visual-auditory multisensory interactions in dyslexia. *Experimental Brain Research,* Vol.166, No.3-4, pp. 474-480, ISSN 1432-1106.

Hari, R., & Kiesilä, P. (1996). Deficit of temporal auditory processing in dyslexic adults. *Neuroscience Letters,* Vol.205, No.2, pp. 138-140, ISSN 0304-3940.

Hari, R., & Renvall, H. (2001). Impaired processing of rapid stimulus sequences in dyslexia. *Trends in Cognitive Sciences,* Vol.5, No.12, pp. 525-532, ISSN 1364-6613.

Hari, R., Renvall, H., & Tanskanen, T. (2001). Left minineglect in dyslexic adults. *Brain,* Vol.124, No.7, pp. 1373-1380, ISSN 1460-2156.

Hari, R., Saaskilahti, A., Helenius, P., & Uutela, K. (1999a). Non-impaired auditory phase locking in dyslexic adults. *Neuroreport,* Vo.10, No.11, pp. 2347-2348, ISSN 0959-4965.

Hari, R., Valta, M., & Uutela, K. (1999b). Prolonged attentional dwell time in dyslexic adults. *Neuroscience Letters,* Vol.271, No.3, pp. 202-204, ISSN 0304-3940.

Heim, S., Freeman, R. B., Jr., Eulitz, C., & Elbert, T. (2001). Auditory temporal processing deficit in dyslexia is associated with enhanced sensitivity in the visual modality. *Neuroreport,* Vol.12, No.3, pp. 507-510, ISSN 0959-4965.

Heim, S., Tschierse, J., Amunts, K., Wilms, M., Vossel, S., Willmes, K., et al. (2008). Cognitive subtypes of dyslexia. *Acta Neurobiologicae Experimentalis,* Vol.68, No.1, pp. 73-89

Helenius, P., Salmelin, R., Service, E., & Connolly, J. F. (1999). Semantic cortical activation in dyslexic readers. *Journal of cognitive neuroscience,* Vol.11, No.5, pp. 535-550, ISSN 1530-8898.

Hood, M., & Conlon, E. (2004). Visual and auditory temporal processing and early reading development. *Dyslexia,* Vo.10, No.3, pp. 234-252, ISSN 1099-0909.

Hulme, C., Hatcher, P. J., Nation, K., Brown, A., Adams, J., & Stuart, G. (2002). Phoneme Awareness Is a Better Predictor of Early Reading Skill Than Onset-Rime Awareness. *Journal of Experimental Child Psychology,* Vol.82, No.1, pp. 2-28, ISSN 0022-0965.

Husain, M., Shapiro, K., Martin, J., & Kennard, C. (1997). Abnormal temporal dynamics of visual attention in spatial neglect patients. *Nature,* Vol.385, No.6612, pp. 154-156, ISSN 1476-4687.

Hutzler, F., Kronbichler, M., Jacobs, A. M., & Wimmer, H. (2006). Perhaps correlational but not causal: no effect of dyslexic readers' magnocellular system on their eye movements during reading. *Neuropsychologia,* Vol.44, *No.*4, pp. 637-648.

Jaskowski, P., & Rusiak, P. (2008). Temporal order judgment in dyslexia. *Psychological Research,* Vol.72, No.1, pp. 65-73, ISSN 1430-2772.

Jones, M. W., Branigan, H. P., & Kelly, M. L. (2008). Visual deficits in developmental dyslexia: relationships between non-linguistic visual tasks and their contribution to components of reading. *Dyslexia,* Vol.14, No.2, pp. 95-115, ISSN 1099-0909.

Kidd, J. C., & Hogben, J. H. (2007). Does the auditory saltation stimulus distinguish dyslexic from competently reading adults? *Journal of Speech, Language and Hearing Research,* Vol.50, No.4, pp. 982-998, ISSN 0022-4685.

Kronbichler, M., Hutzler, F., & Wimmer, H. (2002). Dyslexia: verbal impairments in the absence of magnocellular impairments. *Neuroreport,* Vol.13, No.5, pp. 617-620, ISSN 0959-4965.

Laasonen, M., Service, E., & Virsu, V. (2001). Temporal order and processing acuity of visual, auditory, and tactile perception in developmentally dyslexic young adults. *Cognitive and Affective Behavioral Neurosciences,* Vol.1, No.4, pp. 394-410, ISSN 15307026.

Laasonen, M., Tomma-Halme, J., Lahti-Nuuttila, P., Service, E., & Virsu, V. (2000). Rate of information segregation in developmentally dyslexic children. *Brain & Language,* Vol.75, No.1, pp. 66-81, ISSN 0093-934X.

Lallier, M. (2009). Spécificités des troubles auditivo- et visuo-attentionels dans la dyslexie développementale. Doctoral dissertation, Université Pierre Mendès France, Grenoble, France.

Lallier, M., Berger, C., Donnadieu, S., & Valdois, S. (2010a). A case study of developmental phonological dyslexia: Is the attentional deficit in the perception of rapid stimuli sequences amodal? *Cortex.* Vol.43, No.2, pp. 231-241, ISSN 0010-9452.

Lallier, M., Donnadieu, S., & Valdois, S. (2010b). Visual attentional blink in dyslexic children: parameterizing the deficit. *Vision Research,* Vol.50, pp. 1855-1861, ISSN 0042-6989.

Lallier, M., Donnadieu, S., & Valdois, S. (Under Review a). How much are phonological and visual attention span disorders linked to simultaneous auditory processing deficits in developmental dyslexia? *Annals of Dyslexia,* ISSN 0736-9387

Lallier, M., Carreiras, M., Tainturier, & Thierry, G. (In progress a). Linguistic rhythm shapes auditory temporal attention: Behavioral evidence in Welsh/English bilinguals.

Lallier, M., Tainturier, M. J., Dering, R. B., Donnadieu, S., Valdois, S., & Thierry, G. (2010c). Behavioural and ERPevidence for amodal sluggish attentional shifting in dyslexic adults. *Neuropsychologia,* Vol.48, No.14, pp. 4125-4135, ISSN 0028-3932.

Lallier, M., Thierry, G., & Tainturier, M. J. (Under Review b). On the importance of considering individual profiles when investigating the role of auditory sequential deficits in dyslexia. *Cognition,* ISSN 0010-0277.

Lallier, M., Thierry, G., Valdois, S., & Tainturier, M. J. (In progress b). Is there a link between phonological processing deficits and rapid visual sequential processing deficits in developmental dyslexia?

Lallier, M., Thierry, G., Tainturier, M. J., Donnadieu, S., Peyrin, C., Billard, C., & Valdois, S. (2009). Auditory and visual stream segregation in children and adults: An assessment of the amodality assumption of the 'sluggish attentional shifting' theory. *Brain Research*, Vol.1302, pp. 132-147, ISSN 1872-6348.

Landerl, K. & Willburger, E. (2010). Temporal processing, attention, and learning disorders. *Learning and individual differences*. Vol.5, No.5. (October 2010), pp. 393-401, ISSN 1041-6080.

Livingstone, M. S., Rosen, G. D., Drislane, F. W., & Galaburda, A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Science,* Vol.88, pp. 7943-7947, ISSN 0027-8424.

Liddle, E. B., Jackson, J. M., Rorden, C., & Jackson S. R. (2009). Lateralized temporal order judgment in dyslexia. *Neuropsychologia*, Vol.47, No.14, (December 2009), pp. 3244-3254, ISSN 0028-3932.

Llinas, R. (1993). Is dyslexia a dysynchronia? *Annals of the New York Academy of Sciences,* Vol.682, pp. 48-56, ISSN 1749-6632.

Lobier, M., Przybylski, L., & Valdois, S. (Submitted). Letters in unrelated consonant strings are processed simultaneously.

Lobier, M., Lassus-Sangosse, D., Zoubrinetzki, R. & Valdois, S. (In press). The visual attention span is visual and not verbal. *Cortex*, ISSN 0010-9452.

Lorusso, M. L., Facoetti, A., & Molteni, M. (2004). Hemispheric, attentional, and processing speed factors in the treatment of developmental dyslexia. *Brain & Cognition,* Vol.55, No.2, pp. 341-348, ISSN 0278-2626.

Lorusso, M. L., Facoetti, A., Toraldo, A., & Molteni, M. (2005). Tachistoscopic treatment of dyslexia changes the distribution of visual-spatial attention. *Brain & Cognition,* Vol.57, No.2, pp. 135-142, ISSN 0278-2626.

May, J. G., Williams, M. C., & Dunlap, W. P. (1988). Temporal order judgements in good and poor readers. *Neuropsychologia,* Vol.26, No.6, pp. 917-924, ISSN 0028-3932.

Marshall, J. C. (2001). Auditory neglect and right parietal cortex. *Brain,* Vol.124, No.4, pp. 645-646, ISSN 1460-2156.

McLean, G. M. T., Stuart, G. W., Coltheart, V., Castles, A. (2011) Visual temporal processing in dyslexia and the magnocellular deficit theory: The need for speed? *Journal of Experimental Psychology: Human Perception and Performance*, (August 2011), ISSN 0096-1523.

Meyler, A., & Breznitz, Z. (2005). Visual, auditory and cross-modal processing of linguistic and nonlinguistic temporal patterns among adult dyslexic readers. *Dyslexia,* Vol.11, No.2, pp. 93-115, ISSN 1099-0909.

Pammer, K., Lavis, R., Hansen, P., & Cornelissen, P. L. (2004). Symbol-string sensitivity and children's reading. *Brain & Language,* Vol.89, No.3, pp. 601-610, **ISSN** 0093-934X.

Pammer, K., & Vidyasagar, T. R. (2005). Integration of the visual and auditory networks in dyslexia: a theoretical perspective. *Journal of Research in Reading,* Vol.28, No.3, pp. 320, ISSN 1467-9817.

Pernet, C. Valdois, S., Celsis, P. & Démonet, J.F. (2006). Lateral masking, levels of processing and stimulus category: A comparative study between normal and dyslexic readers, *Neuropsychologia*, 44, 2374-2385.

Peyrin, C., Démonet, J.F., N´Guyen-Morel, M. A., Le Bas, JF & Valdois, S. (2011). Superior parietal lobe dysfunction in a homogeneous group of dyslexic children with a single visual attention span disorder. *Brain and Language*, Vol.118, No.3, pp. 128-138, **ISSN:** 0093-934X

Peyrin, C., Lallier, & Valdois, S. (2008). Visual attention span brain mechanisms in normal and dyslexic readers. In M. Baciu (Ed.), Neuropsychology and cognition of language Behavioural, neuropsychological and neuroimaging studies of spoken and written language (pp. 22-4).

Peyrin, C., Lallier, M., Baciu, M., Démonet, Le Bas, J.F., & Valdois S. (In press). Dissociation of phonological and visuo-attentional processing in dyslexia: FMRI evidence from two case reports. *Brain and Language.*

Poeppel, D. (2003). The analysis of speech in different temporal integration windows: cerebral lateralization as 'asymmetric sampling in time'. *Speech Communication*, Vol.41, pp. 245–255, ISSN 0167-6393.

Ram-Tsur, R., Faust, M., & Zivotofsky, A. Z. (2006). Sequential processing deficits of reading disabled persons is independent of inter-stimulus interval. *Vision Research,* Vol.46, No.22, pp. 3949-3960, ISSN 0042-6989.

Ram-Tsur, R., Faust, M., & Zivotofsky, A. Z. (2008). Poor performance on serial visual tasks in persons with reading disabilities: impaired working memory? *Journal of Learning Disabilities,* Vol.41, No.5, pp. 437-450, ISSN 1538-4780.

Rayner, K., Pollatsek, A., & Bilsky, A. (1995). Can a temporal processing deficit account for dyslexia? *Psychonomic Bulletin & Review,* Vol.2, No.4, pp. 501–507, ISSN 1531-5320.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., et al. (2003). Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain,* Vol.126, No.4, pp. 841-865, ISSN 1460-2156.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of Experimantal Psychology: Human, Perception and Performance,* Vol.18, No.3, pp. 849-860, ISSN 0096-1523.

Reed, M. A. (1989). Speech perception and the discrimination of brief auditory cues in reading disabled children. *Journal of Experimental Child Psychology,* Vol.48, No.2, pp. 270-292, ISSN 0022-0965.

Robertson, E. K., Joanisse, M. F., Desroches, A. S., & Ng, S (2009). Categorical speech perception deficits distinguish language and reading impairments in children. *Developmental Science*, Vol.12, No.5, pp. 753-765, ISSN 1467-7687.

Rouse, H. J., & Wilshire, C. E. (2007). Comparison of phonological and whole-word treatments for two contrasting cases of developmental dyslexia. *Cognitive Neuropsychology,* Vol.24, No.8, pp. 817-842, ISSN 1464-0627.

Schäffler, T., Sonntag, J., Hartnegg, K., & Fischer, B. (2004). The effect of practice on low-level auditory discrimination, phonological skills, and spelling in dyslexia. *Dyslexia,* Vol.10, No.2, pp. 119-130, ISSN 1099-0909.

Share, D. L., Jorm, A. F., Maclean, N. R., & Matthews, R. (2002). Temporal processing and reading disability. *Reading and Writing: An Interdisciplinary Journal,* Vol.15, pp. 151-178, ISSN 0922-4777.

Sireteanu, R., Goebel, C., Goertz, R., & Wandert, T. (2006). Do children with developmental dyslexia show a selective visual attention deficit? *Strabismus,* Vol.14, No.2, pp. 85-93, ISSN 0927-3972.

Sireteanu, R., Goertz, R., Bachert, I., & Wandert, T. (2005). Children with developmental dyslexia show a left visual "minineglect". *Vision Research,* Vol.45, No.25-26, pp. 3075-3082, ISSN 0042-6989.

Skottun, B. C. (2000). On the conflicting support for the magnocellular-deficit theory of dyslexia: Response to Stein, Talcott and Walsh (2000). *Trends in Cognitive Sciences,* Vol.4, No.6, pp. 211-212, ISSN 1364-6613.

Skoyles, J., & Skottun, B. C. (2004). On the prevalence of magnocellular deficits in the visual system of non-dyslexic individuals. *Brain and Language,* Vol.88, No.1, pp. 79-82, **ISSN:** 0093-934X.

Slaghuis, W. L., & Ryan, J. F. (1999). Spatio-temporal contrast sensitivity, coherent motion, and visible persistence in developmental dyslexia. *Vision Research,* Vol.39, No.3, pp. 651-668, ISSN 0042-6989.

Snowling, M. J. (2000). *Dyslexia.* Oxford: Blackwell.

Sperling, A. J., Lu, Z. L., Manis, F. R., & Seidenberg, M. S. (2005). Deficits in perceptual noise exclusion in developmental dyslexia. *Nature Neuroscience*, Vol.8, pp. 862–863, ISSN 1546-1726.

Stein, J., & Talcott, J. (1999). Impaired Neuronal Timing in Developmental Dyslexia-The Magnocellular Hypothesis. *Dyslexia*, Vol.5, pp. 59–77, ISSN 1099-0909.

Stein, J., & Walsh, V. (1997). To see but not to read; the magnocellular theory of dyslexia. *Trends in Neuroscience,* Vol.20, No.4, pp. 147-152, ISSN 1364-6613.

Talcott, J. B., Hansen, P. C., Assoku, E. L., & Stein, J. F. (2000). Visual motion sensitivity in dyslexia: evidence for temporal and energy integration deficits. *Neuropsychologia,* Vol.38, No.7, pp. 935-943, ISSN 0028-3932.

Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language,* Vol.9, No.2, pp. 182-198, **ISSN:** 0093-934X.

Tallal, P., & Piercy, M. (1973). Defects of non-verbal auditory perception in children with developmental aphasia. *Nature,* Vol.241, No.5390, pp. 468-469, ISSN 1476-4687.

Tallal, P., & Piercy, M. (1974). Developmental aphasia: rate of auditory processing and selective impairment of consonant perception. *Neuropsychologia,* Vol.12, No.1, pp. 83-93, ISSN 0028-3932.

Trussell, L. O. (1999). Synaptic mechanisms for coding timing in auditory neurons. *Annual Review of Physiology,* Vol.61, pp. 447-496, ISSN 00664278.

Vachon, F., & Tremblay, S. (2008). Modality-specific and amodal sources of interference in the attentional blink. *Perception & Psychophysics,* Vol.70, No.6, pp. 1000-1015, SSN 0031-5117.

Valdois. S & Bosse, M.L. (Submitted). The phonological and visual attention span bases of orthographic knowledge acquisition.

Valdois, S., Bosse, M. L., Ans, B., Carbonnel, S., Zorman, M., David, D., et al. (2003). Phonological and visual processing deficits can dissociate in developmental

dyslexia: Evidence from two case studies. *Reading and Writing: An interdisciplinary Journal,* Vol.16, pp. 541-572, ISSN 0922-4777.

Valdois, S., Lassus-Sangosse, D. & Lobier, M. (in press). The visual nature of the visual attention span disorder in developmental dyslexia. In J. Stein & Z. Kapula, Visual aspects of dyslexia, Oxford University Press.

Van Ingelghem, M., Van Wieringen, A., Wouters, J., Vandenbussche, E., Onghena, P., & Ghesquière, P. (2001). Psychophysical evidence for a general temporal processing deficit in children with dyslexia. *Neuroreport,* Vol.12, No.16, pp. 3603-3607, ISSN 0959-4965.

Van Noorden, L. P. A. S. (1975). *Temporal coherence in the perception of tone sequences.* Holland, Eindhoven.

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): what have we learned in the past four decades? *Journal of Child Psychology and Psychiatry,* Vol.45, No.1, pp. 2-40, ISSN 1469-7610.

Vidyasagar, T., & Pammer, K. (2010) Dyslexia: a deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive sciences*, Vol.14, No.2, pp. 57-63, ISSN 1364-6613.

Visser, T. A., Boden, C., & Giaschi, D. E. (2004). Children with dyslexia: evidence for visual attention deficits in perception of rapid sequences of objects. *Vision Research,* Vol.44, No.21, pp. 2521-2535, ISSN 0042-6989.

Walker, K. M., Hall, S. E., Klein, R. M., & Phillips, D. P. (2006). Development of perceptual correlates of reading performance. *Brain Research,* Vol.1124, No.1, pp. 126-141, ISSN 1872-6348.

Welch, R. B., DuttonHurt, L. D., & Warren, D. H. (1986). Contributions of audition and vision to temporal rate perception. *Perception & Psychophysics,* Vol.39, No.4, pp. 294-300, SSN 0031-5117.

White, S., Milne, E., Rosen, S., Hansen, P., Swettenham, J., Frith, U., et al. (2006). The role of sensorimotor impairments in dyslexia: a multiple case study of dyslexic children. *Developmental Science,* Vol.9, No.3, pp. 237-255, ISSN 1467-7687.

Witton, C., Richardson, A., Griffiths, T. D., & Rees, A. (1997). Temporal pattern analysis in dyslexia. *British Journal of Audiology,* Vol.31, pp. 100-101, ISSN 1708-8186.

Witton, C., Stein, J. F., Stoodley, C. J., Rosner, B. S., & Talcott, J. B. (2002). Separate influences of acoustic AM and FM sensitivity on the phonological decoding skills of impaired and normal readers. *Journal of Cognitive Neuroscience,* Vol.14, No.6, pp. 866-874, ISSN 1530-8898.

Ziegler, J. C., Pech-Georgel, C., Dufau, S., & Grainger, J. (2010). Rapid processing of letters digits and symbols: What purely visual-attentional deficit in developmental dyslexia? *Developmental Science*, Vol.13, No.4, pp.F8–F14, ISSN 1363755X.
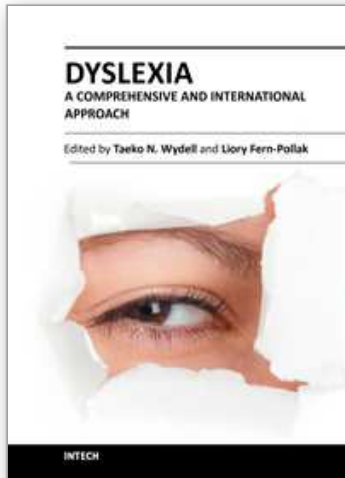
This book brings together dyslexia research from different perspectives and from different parts of the world, with the aim of providing a valuable source of information to medical professionals specializing in paediatrics, audiology, psychiatry and neurology as well as general practitioners, to psychologists who specialise in developmental psychology, clinical psychology or educational psychology, to other professions such as school health professionals and educators, and to those who may be interested in research into developmental dyslexia. It provides a comprehensive overview of Developmental Dyslexia, its clinical presentation, pathophysiology and epidemiology, as well as detailed descriptions of particular aspects of the condition. It covers all aspects of the field from underlying aetiology to currently available, routinely used diagnostic tests and intervention strategies, and addresses important social, cultural and quality of life issues.

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