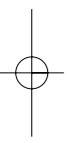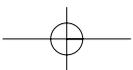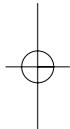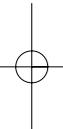PART I

Neurological/Genetic Perspectives

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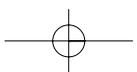
The Origin of Dyslexia:
The Asynchrony Phenomenon

Z v i a   B r e z n i t z

This chapter will

i)   discuss synchronization in speed and content as a factor contributing to fluency in the regular and impaired reading process; and
ii) present an innovative concept for our understanding of dyslexia

Reading is a highly composite cognitive task that involves word decoding and comprehending printed or written materials. Effective word decoding is a prerequisite for comprehension. In most cases, the reading process is successful. However, in approximately 10–15 per cent of the population it is not. Reading failures are commonly termed developmental dyslexia. Different theories have been proposed in an attempt to understand the dyslexia phenomenon. Some theories are descriptive and focus on the inaccuracy and slowness/dysfluency of word reading among dyslexics (see British Psychological Society, 1999: 18 for their definition of dyslexia), while others aim to explain dyslexia (Lyon et al., 2003). An abundance of data has pointed to impairments in phonological processing as the cause of poor word reading (e.g. Share, 1995). The lack of orthographic, semantic, syntactic and morphological skills has also been considered (e.g., see Adams, 1990 for a review). Other evidence has indicated that dyslexia has a neurological basis (Lyon et al., 2003).

  This chapter will present an innovative concept for our understanding of dyslexia, which refers to its foundations. Breznitz's recent Asynchrony Theory proposes that dyslexia is an outcome of the failure to *synchronize* the various brain entities activated during the reading process (see Breznitz, 2002; Breznitz and Misra, 2003; Breznitz, 2006). The asynchrony theory is based on the idea

that the word reading process relies on various sources of information with regard to printed materials. This information arrives from different brain entities. These entities have different biological structures, they are activated in separate areas of the brain, and they process information in a different manner and at different speeds. Furthermore, the reading activity requires the flow of relevant information from one brain area (the posterior lobes) to another (the frontal lobe). Whereas the posterior lobes are responsible for perception and physical processing of a stimulus, the frontal lobe provides meaning and motoric pronunciations to the stimulus (Sousa, 2000). In addition, word decoding relies on the transfer of information between brain hemispheres (Sousa, 2000). The left hemisphere processes information in a sequential manner and specializes in linguistic processing. This hemisphere contains Wernicke's area, where the mental lexicon is stored, and Broca's area, which is responsible for language pronunciation. The right hemisphere for most right handed individuals processes information in a holistic way and specializes in the identification of visual patterns (Sousa, 2000). Reading as a linguistic activity requires work in both hemispheres (Marsolek et al., 1992) and diverse areas of the brain need to communicate in a timely fashion.

Moreover, reading is a cognitive process activated through the various stages of the information processing system, including perception, processing, and output (Atkinson and Shiffrin, 1971). The act of reading must be sufficiently fast to operate within the constraints of limited capacity and rapid decay of the information processing entities (Perfetti, 1985). Above all, word decoding during reading is an inflexible action. In most alphabetic languages each grapheme matches only one phoneme. This grapheme-phoneme correspondence necessitates precision in content and time. This complexity constitutes a major challenge for the human brain as each brain entity activated in this process operates on a different time scale (Breznitz, 2002; Breznitz and Misra, 2003; Breznitz, 2006 for review). As a result, the integration and synchronization in time of the information arriving from the various brain entities, at all levels and stages of activation, is essential for successful word reading to occur.

According to Breznitz (2006), a gap in speed of processing (SOP) between the different brain entities activated in the word decoding process may prevent the precise synchronization of information necessary for an accurate process. This idea lies at the heart of the Asynchrony Theory, which suggests that the wider the SOP gap between the different brain entities; the more severe the word decoding failure will tend to be (Breznitz, 2002; 2006). There are several preconditions for the Asynchrony Phenomenon to occur:

1   more than one system, area of brain activation and/or stage of cognitive operation (referred to as entities) are involved in the processing task;
2   there are differences in the speeds at which each entity processes information;
3   the SOP of the various entities is not sufficiently coordinated to allow effective integration.

ASYNCHRONY THEORY OF DYSLEXIA

More than one entity is involved in the word decoding process

Word decoding relies on different brain entities that can be distinguished on the basis of three levels of involvement in the process:

1   the biological brain systems;
2   the cognitive processes;
3   the alphabetic units of various sizes obtained from printed materials.

The three levels of activation

The biological level

The biological level refers to a domain-general notion of processing, of which reading is considered a part. It consists of several entities activated during reading from the entryway to the human brain along the different stages of activation within and between the various neural pathways of the brain. At the end of this process, it is necessary for the brain to provide a solution, which appears in the form of output accompanied, in many cases, by motoric features. The entities at this level are: the visual and auditory-acoustic modalities. Each entity is represented by specific brain locations and has a different length and structure to its neural pathway, with the visual pathway being longer than the auditory. The visual system processes information in a holistic manner, while processing in the auditory system is sequential. Each contributes to the reading process at a different point in time and at a different speed. The visual entity is the first to start decoding. It is triggered by printed materials and then works in parallel with the auditory entity. The performance of each entity is subject to its intrinsic capabilities, to the successes and failures of other components, and to the manner in which the entities are synchronized in terms of their speed (rapidity) and content (accuracy).

The cognitive processes

The cognitive processes combine two levels of operation, the domain-general and domain-specific processes. The domain-general processes assembled at the biological level are responsible for distinguishing, selecting, perceiving, categorising, storing and retrieving information. The domain-specific processes assembled in the biological modalities activate the orthographic, phonological-recoding and semantic processes, which are specific to the word decoding process. At the initial stage of activation, attention is first allocated to the printed materials prior to the operation of the biological systems (at the entryway), and then different levels of cognitive operation are assembled along with the activation of the biological processes.

The domain-general processes operate sequentially while the domain-specific processes function in an interactive manner until word meaning is obtained (Seidenberg and McClelland's PDP model, 1989; Harm and Seidenberg, 2004). There has been considerable debate concerning the mechanisms involved in mapping word meaning from print. Harm and Seidenberg (2004) attempted to resolve this longstanding debate by constructing and testing a computational model based on connectionist principles. According to this model, the meaning of a word is a 'pattern of activation over a set of semantic units that develops over time based on continuous input from both orth>semantic and orth> phon>semantic components' (p. 663). Unlike previous accounts, in which the two pathways operate independently, in this model, both pathways determine meaning simultaneously, and have a mutual dependency on each other. The performance of each component is subject to both its intrinsic capabilities and the successes and failures of other components. An important assumption incorporated in the model is the notion that the reader's task is to compute meanings both accurately and quickly. Although the orth> phon>semantic pathway has a clear speed disadvantage, as it involves an extra 'step' compared to the direct pathway (orth>semantic), the direct pathway actually takes longer to learn.

The asynchrony theory suggests that in an attempt to process information adequately, the system's speed attribute becomes a crucial factor in the further development of activation in the pathways. Moreover, more than one system is activated in each pathway and as such, synchronization is required and can only be achieved if the SOP gap between systems is minimal.

Furthermore, it is not clear whether there are two pathways that are activated during normal reading development. As during most activities, the brain searches for the most economical way to process information, it is conceivable that there is only one pathway used to process information during reading, that is the indirect pathway (orthography>phonology>semantic) which leads to an effective process. Over the years, the speed at which information is transferred from the orthographic to the semantic system via the phonological system is sped up. In other words, the recoding of printed materials in the phonological system continues to exist throughout, even during advanced word decoding in an inhibitory way, although it becomes very fast, barely manifested and hardly measurable with current available research measures. Furthermore, the act of recoding the linguistic unit in the phonological system has an advantage as it has been trained over the years by two actions: spoken language and reading. It is possible, that the dual training actions of this system assists speed of information processing to the extent that activation of the phonological step becomes hardly noticeable during the normal course of word decoding among skilled readers.

The alphabetic level

The alphabetic level refers to domain-specific processing, which is an objective process, external to the reader and depends on the level of printed materials. The printed material units provide content to the biological and cognitive entities.

This level includes all of the reading-related subtasks triggered by and derived from the printed materials followed by activation in the mental lexicon. It includes all levels of the alphabetic code (letters, sounds, and syllables), the various levels of linguistic units (words and connected text) and their phonological, orthographic, semantic, syntactic and morphological representations and processes. Activation of the biological systems is triggered by these printed linguistic units, and elevates the various forms of processing to the different cognitive levels.

Successful reading requires a form of 'dialogue' between the different brain entities involved in this process. During the normal course of word decoding, the dialogue takes place at different stages of activation along the neural pathways. This places an additional workload on the decoding activity as it requires different levels of synchronization of the brain entities at different points in time. When the decoding skills are not automatic, are less stable, or have yet to progress through the developmental stages, and when the orthographic representations of words in the mental lexicon have yet to stabilize, the various entities are required to cooperate continuously in order to send whatever information is available (even if inaccurate) regarding the linguistic unit being processed. In an impaired or undeveloped word decoding process, the information in one or more entities may not be completely accurate or available. This may constitute an additional obstacle for precise synchronization between entities. Moreover, partial or incomplete input from one entity might diminish the incoming information arriving in the other entities.

Word decoding complexity is increased further by the fact that from an evolutionary perspective, the human brain has existed for around 60,000 years, and the alphabetic code for only 5000 years. Consequently, the ability to read is not part of our evolutionary heritage. No biological brain system has been developed specifically for the reading process, so the activation of reading must rely on systems that were developed for different tasks. This complexity poses a major challenge for the human brain, and proves too much for some readers.

Speed of processing differences between different brain entities

What are the speeds of processing of the brain entities involved in word decoding? Research indicates that non-linguistic auditory information arrives in the auditory cortex after 30 ms (Heil et al., 1999), whereas visual information arrives in the visual cortex after 70 ms (Schmolesky et al., 1998). In other words, based on the natural operation of these biological entities, auditory stimuli leave the 'entryway' and arrive in the brain faster than visual stimuli. This may be due to the different lengths of the neural pathways, brain sites and structures of each modality. However, at the linguistic level there is evidence that at least from the word level onwards, linguistic information is processed in the auditory channel in a temporal-serial manner. In other words, the information concerning the

phonemes that make up a word arrives sequentially over time (Rosenzweig and Bennett, 1996). In contrast, word processing in the visual channel is a holistic and simultaneous process (Willows et al., 1993), suggesting that visual processing at this level might be faster than auditory.

It is important to note that most existing studies have used behavioural measures of reaction time. This means that the information concerning this entire sequence of cognitive activity has only been provided at the conclusion of processing; in the reader's output. This stage only occurs after the completion of sensory, cognitive and motor processes (Bentin, 1989; Brandeis and Lehmann, 1994; Johnson, 1995). This makes it difficult to determine, on the basis of behavioural measures alone, the extent to which dysfunction or slowness at any particular stage of processing contributes to reading deficits.

pIn recent years, new methods based on electrophysiological parameters utilizing electroencephalogram (EEG) data have been used in reading research. The EEG method is used to assess on-line processing of cognitive activity. It has been used for the following activities:

1   Measurement of event-related potentials (ERPs). This method permits direct observation of information processing at different levels of analysis, and can provide crucial information by means of real-time imaging of the neural system's responses to sensory stimulation (Bentin, 1989). Thus, it enables us to trace on-line the speed at which information is processed during the various cognitive stages of the reading activity. ERPs are extracted from EEG data by averaging brain responses during a number of equivalent trials in a given experiment. ERPs consist of various discrete components, or brain waves, that can be related to different stages of information processing in terms of amplitude and/or latency variations.

2   Estimation of the brain source of ERP's latencies using Low Resolution Electromagnetic Tomography (LORETA) (Pascual-Marqui et al., 1994; Pascual-Marqui, 1999).

3   Estimation of brain connectivity (Malsburg and von der Schneider, 1986; Abarbanel et al., 1996), namely, the manner in which cortical areas act in concert with each other.

By using these methodologies, it is possible to systematically examine the speed of processing (SOP) of the different entities active during word decoding (Breznitz, 2002; 2003; Breznitz and Meyler, 2003; Breznitz and Misra, 2003; Barnea and Breznitz, 1998; Breznitz, 2005; Breznitz, 2006 for review). In these studies, SOP within and between the visual and auditory modalities, and speed of information transfer between different brain areas and at different stages of cognitive activation were measured. In the different experiments, lower level non-linguistic tasks (SOP for tones and flashes) and linguistic tasks (letters and syllables) as well as higher level linguistic (words, pseudowords and sentences) tasks were examined. The stimuli were presented separately as well as simultaneously in the two modalities. The subjects in these experiments consisted of different age groups of dyslexic and regular readers, young fourth to fifth grade children and adult university students (see Breznitz 2006 for

a comprehensive review). These experiments measured SOP using Reaction Time (RT) and ERP latencies. Across the different experiments, the various ERP components were identified. However, two ERP components were systematically recognized across all experiments in both age groups:

1   An early P100-P200 complex, which is thought to index mechanisms of sensory activity elicited by a stimulus (Johnstone et al., 1996; Tonnquist-Uhlen, 1996) such as feature detection (e.g., Luck and Hillyard, 1994), selective attention (e.g., Hackley et al., 1990) and other early sensory stages of item encoding (Dunn et al., 1998).
2   P300, which is considered to be a valid index of central information processing during task-related decision-making (Palmer et al., 1994). Processes associated with P300 include the dynamic updating of information held in working memory (Israel et al., 1980; Fitzgerald and Picton, 1983), cognitive resource allocation and task involvement) Kramer et al., 1991), as well as mental effort or workload (Humphrey and Kramer, 1994; Wilson et al., 1998).

Visual and auditory SOP

Figures 1–6 summarize the results of a wide range of studies (see Breznitz 2006 for more detail) in which the processing times of visual and auditory stimuli at different levels of complexity were measured in the research population. The results of the experiments carried out among young readers are summarized in Figures 1–3, and among adults in Figures 4–6.
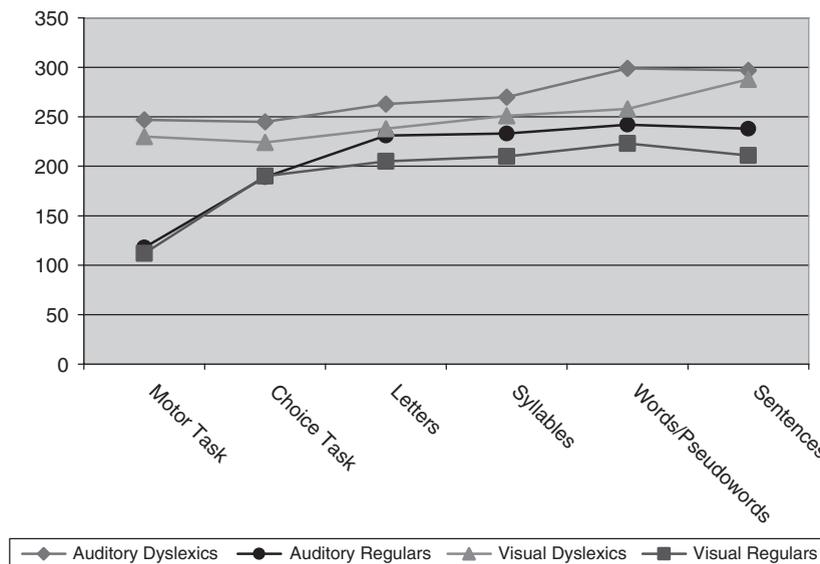
Young regular and dyslexic readers

Figure 1   The perception stage (P100-200 complex at CZ electrodes)
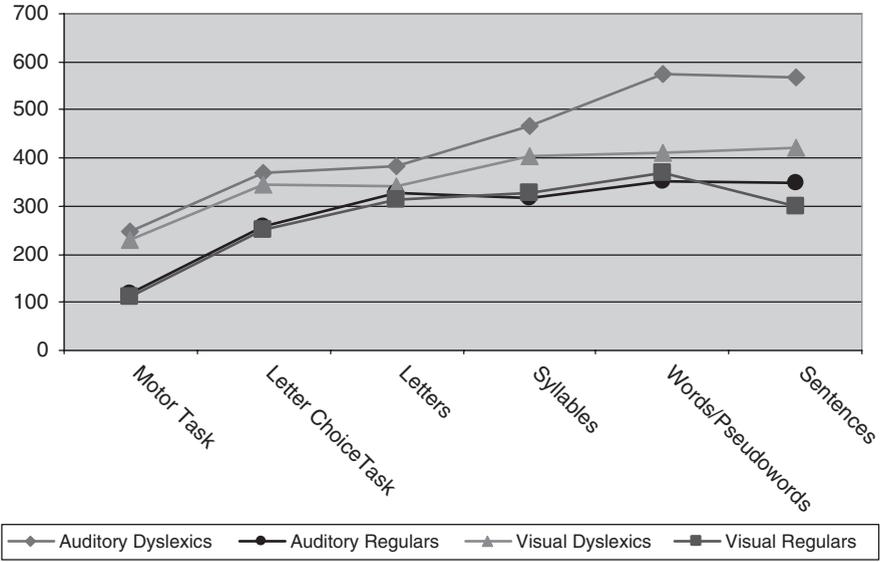
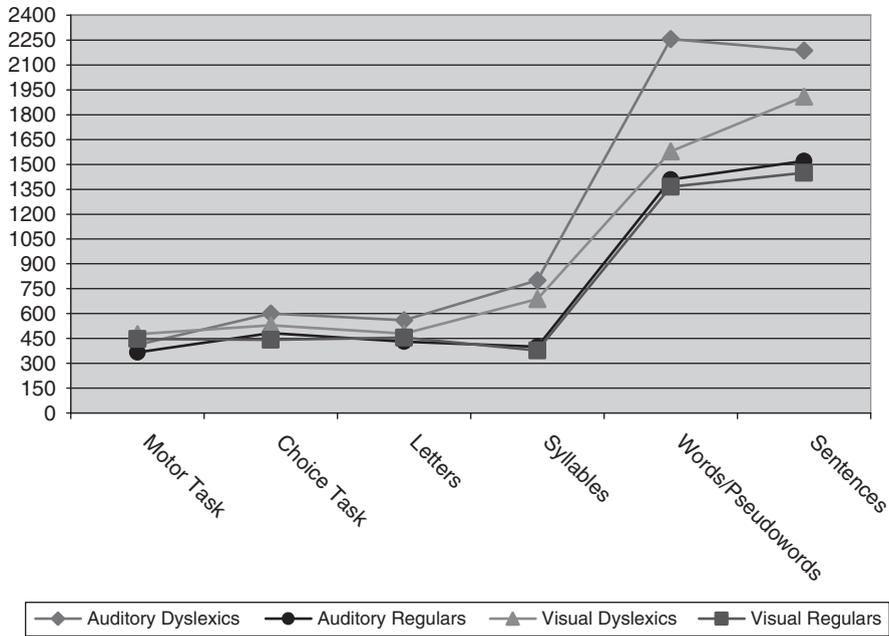**Figure 2   The processing stage (P300 at CZ electrode)**

Figure 3   The output stage (reaction time)

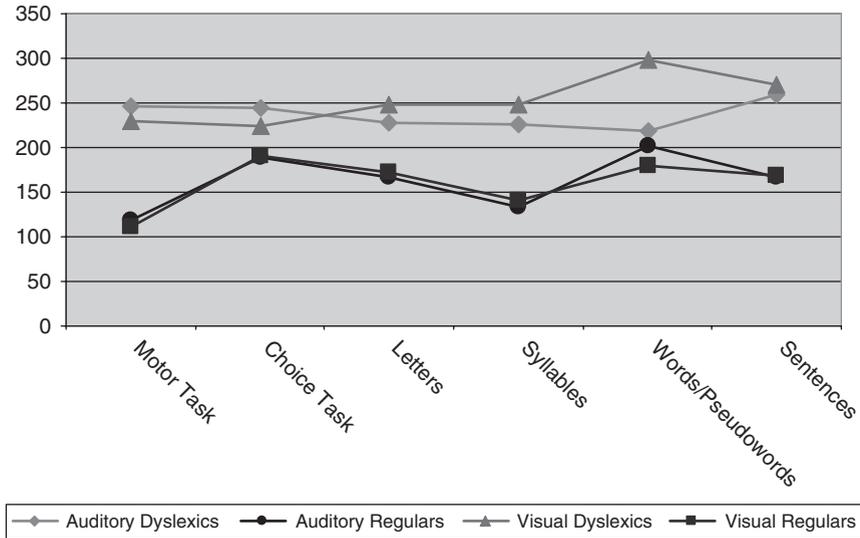*Adult regular and dyslexic readers*

Figure 4   The perception stage (P100-200 complex at CZ electrodes)
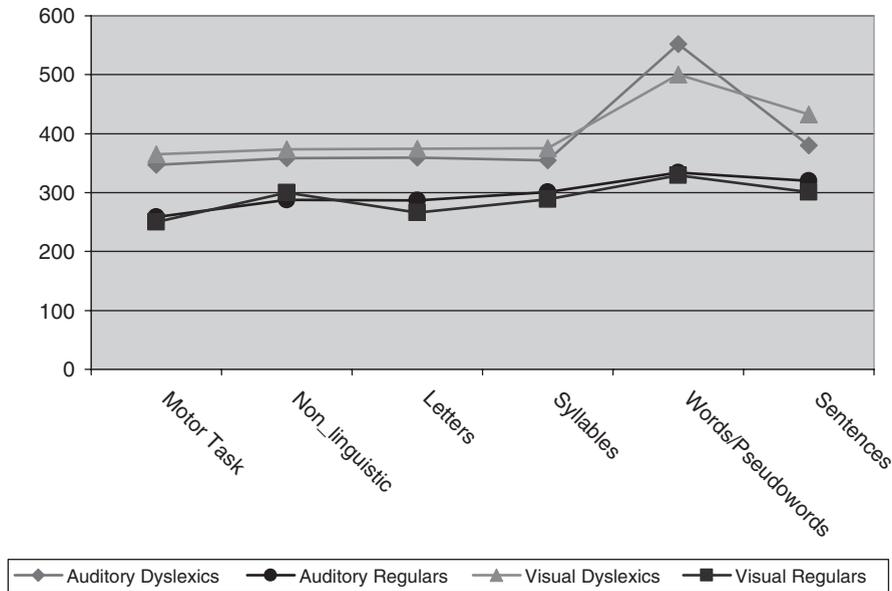

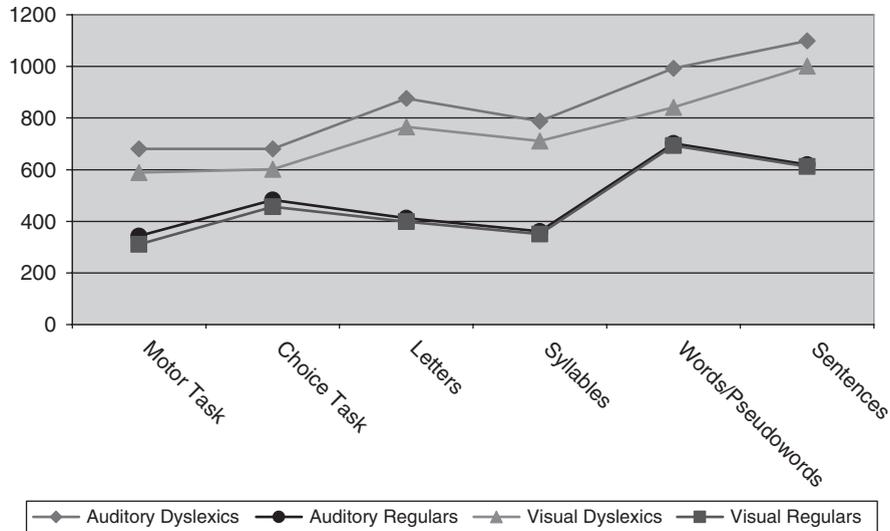**Figure 5   The processing stage (P300 at CZ electrode)**

Figure 6   The output stage (reaction time)

Examination of speed of processing among the brain entities of young and adult dyslexic and regular readers using behavioural measures and ERP methodology indicated that dyslexics of all ages were significantly slower than the regular readers. This was true at all stages of information processing and at most levels of activation, in processing both visual and auditory information. The differences between both groups of readers in both age groups increased with task complexity. However, close observation of our data shows that during the normal course of processing information there is a natural gap in the speeds at which each modality processes information. Nevertheless, a wider SOP gap was observed among the dyslexics (Breznitz, 2006). Among the young and adult regular and dyslexic readers, auditory processing was slower than visual on most tasks at all levels of activation except for P100-P200 latencies at the linguistic level (letter, syllables and words/pseudoword decision tasks). At this level, the SOP in the visual modality among adult dyslexics was slower than in the auditory modality. Since decoding any linguistic unit begins with the visual modality it is conceivable that over the years, in order to improve their accuracy, the dyslexics trained their brain to perceive linguistic units from printed materials more slowly, following the logic that slowness implies greater attention and increases accuracy. This suggests that the way in which the linguistic unit enters the gateway to the brain might be a crucial factor in enhancing the decoding process. The idea proposed here is that over the years, any linguistic unit of any size develops not only orthographic patterns but also 'visual speed anagrams'.

What is the speed anagram? I would like to suggest that in addition to the orthographic, phonological and semantic aspects of the word there is another

separate independent feature that is also decoded, which relates to the speed at which the reader's visual modality receives printed words. At the initial, perceptual stage of processing, the speed at which the linguistic unit is perceived places a marker (imprint) on the way that the word is formed. This speed marker results from the interaction between the characteristics (including SOP) of the reader's visual modality, his/her reading level and the level of printed materials. At this initial stage of processing, the visual speed anagram is formed and affects the manner in which the linguistic unit enters the brain's entryway, is processed in the different brain entities, and is stored in or retrieved from the mental lexicon.

As 'speed' is a measure of time, it is subject to change. With experience, the speed anagram of each individual orthographic pattern becomes faster until it reaches automaticity and becomes more flexible to accommodate to the readers needs. However, based on the hesitant habits acquired by dyslexic readers in terms of the way they receive linguistic units via the visual modality, this 'visual speed anagram' remains slow and imprints a disrupted marker on the speed at which the various entities process the linguistic unit. The outcome of this impaired process is the creation of an inflexible, non-automatic and inconsistent word decoding process. Nevertheless, based on the plasticity of the brain to change, our research on the acceleration phenomenon has indicated that even the brains of dyslexic readers can be accelerated to create and retrieve linguistic units at the levels of words and sentences. In other words, the 'speed anagram' of the orthographic unit in this population can be improved by training and direct intervention (Breznitz, 2006; Breznitz and Berman, 2003).

Asynchrony between the posterior and anterior brain sites

The word reading process relies on both anterior and posterior brain areas (Sousa, 2000). In the anterior region, there are two crucial centers responsible for linguistic processes. Broca's center is responsible for pronunciation of stimuli and for changing orthographic information into its phonological form (Hagoort et al., 1999; Fiez et al., 1999). Wernicke's center stores the mental lexicon. In the posterior region, three perceptual lobes are located: the occipital lobe for visual information, the temporal lobe for auditory, and the parietal lobe for motoric processing. These lobes operate separately or in conjunction, depending on the requirements of the task (Petersen et al., 1988; Rumsey et al., 1997).

A study examining cerebral activity during reading found that processing began in the visual area of the occipital lobe 100 ms post stimulus presentation and moved toward the joint between the occipital and temporal lobes in both hemispheres (around 150–200 ms post stimulus presentation) (Salmelin et al., 1996). In the next stage of the reading process, the information was transferred to the superior temporal cortex in the left hemisphere only and to the motor cortex in both hemispheres (between 200–400 ms post stimulus presentations).

It can be concluded that a precise reading process involves the transfer of information from the posterior to anterior brain areas, which takes about 300 ms (see Shaul, 2006). Whether the same pathway and the same time framework applies to dyslexic readers is yet another question. Studies examining differences in cerebral activity between regular and dyslexic readers found significant differences in all activity areas related to reading. There is less activity in the posterior brain sites among dyslexics as compared to regular readers when reading words (Brunswick et al., 1999; Paulesu et al., 2001; Pugh et al., 2000). This finding was corroborated across various languages (Paulesu et al., 2001; Salmelin et al., 1996). In addition, a strong functional connectivity between the posterior areas and Broca's area (left anterior brain site) was found in regular readers. This suggests accurate integration between the orthographic form of the word and its phonological counterpart received in Broca's area. In contrast, the dyslexic readers exhibited connections between posterior areas and pre-frontal areas in the right hemisphere, which is considered to be related to long-term memory (Fletcher et al., 1994). The impaired transfer from the posterior to anterior brain sites among dyslexics may indicate a further delay in the synchronization of orthographic and phonological information during word decoding.

Shaul and Breznitz (under review) investigated the SOP of information transfer from the posterior to anterior brain sites among adult dyslexics as compared to regular readers during performance of a lexical decision task. The study employed ERP methodology, and analysis was performed by comparing pairs of electrodes situated in similar sites in the posterior and anterior regions of the brain (i.e., FP1–O1, F7–P7, F3–P3, FZ–PZ, F4–P4, F8–P8, FP2–O2). Among dyslexics, at the perceptual level (P200) information arrived about 11–12 ms later from the posterior to anterior brain areas. Among regular readers, this delay was limited to 3–4 ms.

Asynchrony between the left and right hemispheres

The human brain is divided into two hemispheres, the right and the left. Even though the two hemispheres appear identical they differ in the number and size of their neurons and in the amount of various neurotransmitters (Banich, 2004). Apart from the structural and chemical differences, each hemisphere specializes in specific abilities. The right hemisphere specializes in pattern recognition, creativity, spatial orientation, face and object recognition as well as emotion and processing of internal information. The left hemisphere is responsible for analysis, language skills (speaking, letter and word recognition), sequence and number recognition, sensitivity to time and processing of external information (Carter, 1998). Each hemisphere receives information from the opposite perceptual field and controls the opposite side of the body (Carter, 1998). Tasks with a heavy cognitive load, such as reading, require cooperation and integration in time of information from both hemispheres (Markee et al., 1996). The transfer time of information between hemispheres among adults ranges from 5–20 ms

(Banich, 2004). However, dyslexics exhibit difficulties when transferring information from one hemisphere to another (e.g., Gladstone and Best, 1985; Gladstone et al., 1989; Gross-Glenn and Rothenberg, 1984; Velay et al., 2002; Markee et al., 1996). The differences in inter-hemisphere transfer among dyslexics may stem from information decay in the corpus collosum or a long non-symmetrical delay in inter-hemisphere transfer time measured by IHTT (Inter-hemispheric time transfer). (Davidson et al., 1990; Davidson and Saron 1992; Markee et al., 1996)

Shaul and Breznitz (under review) measured information transfer between the left and right hemispheres among dyslexics as compared to regular readers when performing various lexical decision tasks. Using the IHTT method, the latencies of electrodes situated in similar sites in left and right brain locations were compared (i.e. FP1–FP2, F7–F8, F3–F4, FC5–FC6, T7–T8, C3–C4, CP5–CP6, P7–P8, P3–P4, O1–O2). When stimuli were presented visually to the center of the computer screen, information reflected by the P200 and P300 ERP components arrived among dyslexics in the right hemisphere, at first, and was then transferred approximately 9–12 ms later to the left hemisphere. Among regular readers, the information arrived in the left hemisphere first and was transferred to the right approximately 4–6 ms later. Support for these results was obtained by estimates from source localization of brain activity in these two reading groups during the word decoding process using Low Resolution Electromagnetic Tomography (LORETA – Pascual-Marqui et al., 1994; Pascual-Marqui, 1999) (see Figure 7). Comparisons between groups revealed greater activation among dyslexic readers between 110 and 140 ms for words, mainly in the right temporal and perisylvian regions, as well as some activation in medial frontal regions. Regular readers exhibited greater activation in left temporal

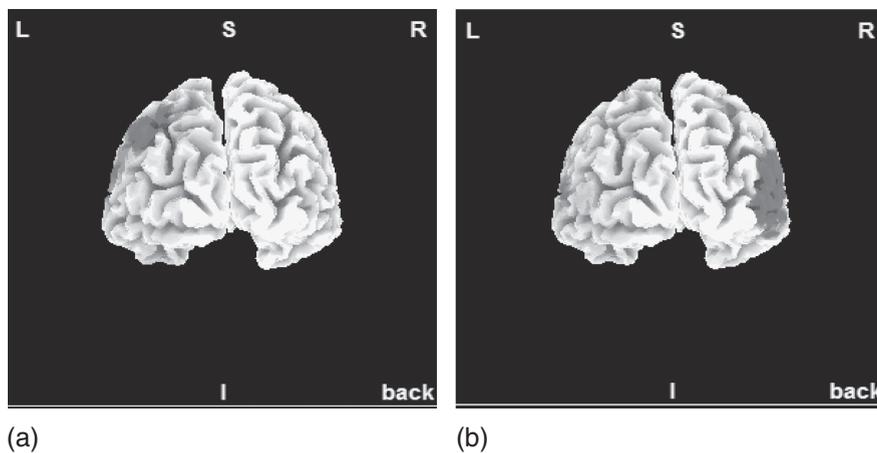(a)   (b)

Figure 7   LORETA resolution for P200 component peak among regular and dyslexic readers during word decoding. a)Regular readers, P200 at 197 ms; b)Dyslexic readers, P200 at 289 ms.

and perisylvian regions between 150 and 200 ms. As all our subjects were
right-handed it seems that the flow of incoming information in the dyslexic
group started in right brain sites and moved to the left, and then again to the
right. We argue that this manner of processing extends the decoding process
among dyslexic readers. Support for this idea can be derived from our reaction
time data. The reaction times of the dyslexic readers during word decoding were
about 121 ms longer than for the regular readers (X = 811.02 s.d = 55.16 among
the dyslexics, and X = 690.13 s.d = 31.12 among the regular readers).

SOP of the various brain entities is not sufficiently coordinated to allow for an effective decoding process

Observation of the results from the different experiments (shown in Figures 1–6
and Table 1) suggests that SOP at all levels of activation is slower among young
and adult dyslexics as compared to regular readers. However, the gap between
the speed of processing (SOP) of the visual and auditory modalities was wider
among dyslexics on most of the experimental tasks and across age groups. The
posterior-anterior SOP gap as well as the SOP gap in information transfer
between hemispheres during lexical decision performance was also wider
among the dyslexics as compared to the controls. Moreover, Figure 7 shows that
the peak of the P200 component among regular readers was observed at 197 ms
in the left hemisphere whereas among dyslexic readers the P200 component
peak was observed at 289 ms in the right hemisphere. Among regular readers,
later activation was observed in the right hemisphere at about 203 ms while
among dyslexic readers, later activation was observed in the left hemisphere at
about 303 ms. This data indicates not only that the P200 appears later among
dyslexics as compared to regular readers but that there is an additional aspect of
between hemisphere asynchrony in the brain activity of dyslexic readers due to
the fact that precise P200 activation occurs in the left hemisphere as opposed
to the right among dyslexics.

Table 1   Reaction time, latencies of the ERP components and Gap scores for the word decoding process among adult readers

	Dyslexics (N=60)			Regular Readers (N=60)		
	Visual	*Auditory*	*GAP*	*Visual*	*Auditory*	*GAP*
P2	298	218	−20	180	202	22
P3	501	559	58	320	334	14
RT	841	993	152	690	702	12
P3-P2 Gap	202	334		140	132	
	Posterior	*Anterior*	*GAP*	*Posterior*	*Anterior*	*GAP*
P2	286	299	15	176	180	4
P3	495	511	16	356	362	6
	Left Hems.	*Right Hems.*	*GAP*	*Left Hems.*	*Right Hems.*	*GAP*
P2	303	289	14	197	203	6
P3	509	495	14	361	364	3

However, support for the asynchrony theory was mainly obtained from the analysis performed to clarify whether the direct SOP of the entities or the between-entity SOP gap accounts for most of the variance in the word decoding process. Regression analysis indicated that of all the measures employed in the experiments the gap between visual and auditory processing accounts for most of the variance in the word decoding process (see Breznitz, 2002; Breznitz and Misra, 2003; Breznitz, 2006 for review and Shaul and Breznitz, under review). Among the young dyslexics, the first predictor was the SOP gap score between grapheme (visual presentation) and phoneme (auditory presentation) at the perceptual stage (P200 latency), and a second predictor was speed of activation during the processing stage (P300) (see Breznitz, 2002). Both variables explained about 72 per cent of the variance in word decoding. Among the adults, the first predictor was the SOP gap score between visual and auditory presentation at the perceptual (P200) level for words, and the second was the processing stage GAP (P300). Both explain 64 per cent of the variance in word decoding (see Breznitz, 2006).

How is the synchronization and asynchrony manifested during word decoding? Ballan (in preparation) measured brain connectivity during the word decoding process using coherence analysis among dyslexic and regular readers. Strong connectivity between the majority of brain areas was found among regular readers for lower level brain wave bands 4–12 Hz. The connectivity was mainly exhibited between the two hemispheres and the posterior and anterior brain sites. Among the dyslexics, moderate connectivity was found within the left hemisphere only at the lower beta band level (13–18 Hz). It is possible that limiting the between entity SOP gap may lead to better brain connectivity and to better brain synchronization. A wider SOP gap may lead to asynchrony between brain entities and therefore to reduced brain connectivity. In other words, effective word decoding may require overall brain activation but for a short period of time. In such a process, all the entities activated during the process are directed to the tasks, thereby reducing distractibility.

SUMMARY

The complex process of word decoding can be compared to a concert in which each musical instrument is playing the same tune, but with a different sound. In order to produce uniform output, the conductor must orchestrate the different musicians so as to synchronize the various sounds of each instrument and to make the output harmonious. Reading similarly requires one specific 'harmonized' output. This process is also based on the activation of different brain entities (instruments), which are located in different areas of the brain (orchestra), and which process information in a different manner (sounds). However, our data indicate that a crucial initial condition for accurate word decoding regards the speed at which each entity is activated. Different brain entities operate on different time scales, which necessitate synchronization.

A wider between-entity SOP gap occurs among dyslexic readers, which leads to the Asynchrony Phenomenon.

The asynchrony in the impaired word decoding process begins with the creation of an impaired 'visual speed anagram' for the linguistic unit at the 'entryway' which affects and opens a speed gap between the different brain entities that are activated during word decoding. Moreover, among dyslexic readers this impaired word form continues on into the wrong (right) hemisphere in the brain. With the idea that the slower the reading rate, the more accurate the activation, during the course of their experience with decoding failures, dyslexic readers may attempt to compensate for their inaccuracy by adopting a inflexible, slower speed of visual processing. As a result, an accumulative between-modality gap opens up and continues along all stages of activation. This affects the flow of information from posterior to anterior brain areas and slows down inter-hemisphere transfer. Perversely, therefore, the adaptation of dyslexic readers to their failures may actually contribute to their reading dysfluency.

The notion that dyslexia is caused by an SOP gap within and between the various entities taking part in the word decoding process, together with the fact that SOP is a time based measure, led us to develop the Reading Acceleration training program (RAP) (Breznitz and Navat, 2004). This program attempted to train the brain to process information at a faster speed and resulted in a substantial improvement among dyslexics in the speed at which information was processed (Breznitz and Itzchak, 2005; Breznitz, 2006, Breznitz and Horowitz, under review). Moreover, this improvement was successfully transferred, as indicated by the enhanced decoding quality and decreased reading times for material not included in the training program. In addition, this progress was also indicated by the early elicitation of the P200 component post-training. We argue that at least for adult dyslexic readers there is a discrepancy between their ability and their performance during word decoding. This discrepancy is an outcome of poor reading habits and an inflexible brain monitor (See Breznitz 2006 for more details), and appears mainly in the speed at which words are decoded. As a result, we suggest a short-term intervention program that directly targets the SOP of the entities activated in the word decoding process, which may reduce the asynchrony phenomenon.

In sum, based on the idea of the plasticity of the brain to change (Sousa, 2004), a properly designed, direct short-term training intervention program instead of an overall remediation program that targets a specific decoding sub-skill, promises to constitute a major contribution to the reduction of dyslexia in the years to come.

REFERENCES

Adams, M. J. (1990) *Beginning to read: Thinking and learning about print.* Cambridge, MA: MIT Press.
Atkinson, R.C. and Shiffrin, R.M. (1971) 'The control of short-term memory', *Scientific American*, 225: 82–90.

Ballan, E. (in preparation) 'Large Scale Neuronal Coordination in Reading: A Comparison between Regular and Dyslexic Readers'.

Banich, M. T. (2004) *Cognitive Neuroscience and Neuropsychology*. Boston MA: Houghton Mifflin Company.

Barnea, A. and Breznitz, Z. (1998) 'Phonological and orthographic processing of Hebrew words: Electrophysiological aspects', *Journal of Genetic Psychology*, 159 (4): 492–504.

Bentin, S. (1989) 'Electrophysiological studies of visual word perception, lexical organization, and semantic processing: A tutorial review', *Language and Speech*, 32: 205–220.

Brandeis, D. and Lehmann, D. (1994) 'ERP mapping: a tool for assessing language disorders', in H. J. Heinze, T. F. Mante and G. R. Mangun (eds), *Cognitive Electrophysiology*. Boston: Birkhauser. pp. 242–250.

Breznitz, Z. (2002)'Asynchrony of visual-orthographic and auditory-phonological word recognition processes: An underlying factor in dyslexia', *Reading and Writing*, 15 (1–2): 15–42.

Breznitz, Z. (2003) 'Speed of phonological and orthographic processing as factors in dyslexia: Electrophysiological evidence', *Genetic, Social and General Psychology Monographs*, 129 (2): 183–206.

Breznitz, Z. (2005) 'Brain activity during performance of naming tasks: Comparison between dyslexic and regular readers', *Scientific Studies of Reading*, 9 (1): 17–42.

Breznitz, Z. (2006) *Fluency in Reading: Synchronization of Processes*. Mahwah, NJ: Lawrence Erlbaum and Associates.

Breznitz, Z. and Berman, L. (2003) 'The underlying factors of word reading rate', *Educational Psychology Review*, 15 (3): 247–265.

Breznitz, Z. and Meyler, A. (2003) 'Speed of lower-level auditory and visual processing as a basic factor in dyslexia: Electrophysiological evidence', *Brain and Language*, 85 (1): 166–184.

Breznitz, Z., and Misra, M. (2003) 'Speed of processing of the visual-orthographic and auditory-phonological systems in adult dyslexics: The contribution of "asynchrony" to word recognition deficits', *Brain and Language*, 85 (3): 486–502.

Breznitz, Z. and Itzhak, Y. (2005) *MA Thesis in Preparation*. University of Haifa. Israel.

Breznitz, Z. and Navat, M. (2004) *Reading Acceleration Program (RAP)*. Unpublished Training Program. University of Haifa.

Breznitz, Z. and Horowitz, T. (under review) 'All the Wrong and Rights Moves: A comparison of cerebral activity during accurate and erroneous reading performance among dyslexics and regular readers, an ERP study'.

British Psychological Society (1999) 'Dyslexia literacy and psychological assessment'. *Report by a working party of the division of educational and child psychology*. Leicester: British Psychological Society.

Brunswick, N., McCrory, E., Price, C. J., Frith, C. D. and Frith, U. (1999) 'Explicit and implicit processing of words and pseudowords by adult developmental dyslexics', *Brain*, 122: 1901–1917.

Carter, R. (1998) *Mapping the Mind*. Los Angeles: University of California Press.

Davidson, R. J., Leslie, S. C.,and Saron, C. D. (1990) 'Reaction time measures of interhemispheric transfer time in reading disabled and normal children', *Neuropsychologia*, 28: 471–485.

Davidson, R. J. and Saron, C. D. (1992) 'Evoked potential measures of interhemispheric transfer time in reading disabled and normal children', *Developmental Neuropsychology*, 8: 261–277.

Dunn, B.R., Dunn, D.A., Languis, M., and Andrews, D., (1998) 'The relation of ERP components to complex memory processing', *Brain and Cognition*, 36: 355–376.

Fiez, J. A., Balota, D. A., Raichle, M. E. and Petersen, S. E. (1999) 'Effects of lexicality, frequency, and spelling-to-sound consistency on the functional anatomy of reading', *Neuron*, 24: 205–218.

Fitzgerald, P. G. and Picton. T. W. (1983) 'Event-related potentials recorded during the discrimination of improbable stimuli', *Biological Psychology*, 17: 241–276.

Fletcher, J. M., Shaywitz, S. E., Shankweiler, D. P., Katz, L., Liberman, I. Y., Steubing, K. K., Francis, D. J., Fowler, A. E. and Shaywitz, B. A. (1994) 'Cognitive profiles of reading disability: Comparisons of discrepancy and low achievement definitions', *Journal of Educational Psychology*, 86: 6–23.

Gladstone, M. and Best, C. T. (1985) 'Developmental dyslexia: the potential role of interhemispheric collaboration in reading acquisition', in C. T. Best (ed) *Hemispheric Function and Collaboration in the Child*. San Francisco: Academic Press. pp. 87–118.

Gladstone, M., Best, C. T. and Davidson, R. J. (1989) 'Anomalous bimanual coordination among dyslexic boys', *Developmental Psychology*, 25: 236–246.

Gross-Glen, K. and Rothenberg, S. (1984) 'Evidence for deficit in interhemispheric transfer of information in dyslexic boys', *International Journal of Neuroscience*, 24: 23–35.

Hackley, S.A., Woldorff, M. and Hillyard, S.A. (1990) 'Cross-modal selective attention effects on retinal, myogenic, brainstem, and cerebral evoked potentials', *Psychophysiology*, 27: 195–28.

Hagoort, P., Indefrey, P., Brown, C., Herzog, H., Steinmetz, H. and Seitz, R. J. (1999) 'The neural circuitry involved in the reading of German words and pseudowords: APET study', *Journal of Cognitive Neuroscience*, 11: 383–398.

Harm, M. and Seidenberg, M. S. (2004) 'Computing the meanings of words in reading: Cooperative division of labor between visual and phonological processes', *Psychological Review*, 111: 662–720.

Heil, M., Rolke, B., Engelkamp, J., Roesler, F., Oezcan, M. and Hennighausen, E. (1999) 'Event-related brain potentials during recognition of ordinary and bizarre action phrases following verbal and subject-performed encoding conditions', *European Journal of Cognitive Psychology*, 11 (2): 261–280.

Israel, J. B., Chesney, G. L., Wickens, C.D. and Donchin, E. (1980) 'P300 and tracking difficulty: Evidence for multiple resources in dual-task performance', *Psychophysiology*, 17 (3): 259–273.

Johnson, R. (1995) 'Effects of color on children's naming of picture', *Perceptual and Motor Skills*, 80: 1091–1101.

Johnstone, S.J., Barry, R.J., Anderson, J.W. and Coyle, S.F. (1996) 'Age-related changes in child and adolescent event-related potential component morphology, amplitude and latency to standard and target stimuli in an auditory oddball task', *International Journal of Psychophysiology*, 24: 223–238.

Kramer, A. F., Strayer, D. L. and Buckley, J. (1991) 'Task versus component consistency in the development of automatic processing: A psychophysiological assessment', *Psychophysiology*, 28 (4): 425–437.

Luck, S. J. and Hillyard, S. A. (1994) 'Electrophysiological correlates of feature analysis during visual search', *Psychophysiology*, 31: 291–308.

Lyon, G. R., Shaywitz, S. E. and Shaywitz, B. A. (2003) 'A definition of dyslexia', *Annals of Dyslexia*, 53: 1–14.

Malsburg, C. and von der, Schneider, W. (1986) 'A neural cocktail party processor', *Biological Cybernetics*, 54: 29–40.

Markee, T., Warren, S. B., Morre, L. H. and Theberge, D.C. (1996) 'Callosal Function in Dyslexia: Evoked Potential Interhemispheric Transfer Time and Bilateral Field Advantage', *Developmental Neuropsychology*, 12: 409–428.

Marsolek, C. J., Kosslyn, S. M. and Squire, L.R. (1992) 'Form-specific visual priming in the right cerebral hemisphere', *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18: 492–508.

Palmer, B., Nasman, V. T. and Wilson, G. F. (1994) 'Task detection difficulty: Effects on ERPs in a same-different letter classification task', *Biological Psychology*, 38 (2–3), 199–214.

Pascual-Marqui, R.D., Michel C.M. and Lehmann, D. (1994) 'Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain', *International Journal of Psychophysiology*, 18 (1): 49–65.

Pascual-Marqui, R.D. (1999) 'Review of methods for solving the EEG inverse problem', *International Journal of Bioelectromagnetism*, 1: 75–86.

Paulesu, E., Démonet, J. F., Fazio, F., McCrory, E., Chanoine, V., Brunswick, N., Cappa, S. F., Cossu, G., Habib, M., Frith, C. D. and Frith, U. (2001) Dyslexia: Cultural diversity and biological unity. *Science, 291,* 2165–2167.

Perfetti, C. (1985) *Reading ability*. NY:Oxford University Press.

Petersen, S.E., Fox, P.T., Posner, M.I., Mintun, M. and Raichle, M.E. (1988) 'Positron emission tomographic studies of the cortical anatomy of single word processing', *Nature*, 331: 585–589.

Pugh, K. R., Mencl, W. E., Jenner, A. R., Katz, L., Frost, S. J., Lee, J. R., Shaywitz, S. E. and Shaywitz, B. A. (2001) 'Neurobiological studies of reading and reading disability', *Journal of Communication Disorders*, 34: 479–492.

Rosenzweig, M. R. and Bennett, E. L. (1996) 'Psychobiology of plasticity: Effects of training and experience on brain and behavior', *Behavioural Brain Research*, 78: 57–65.

Rumsey, J. M., Donohue, B. C., Brady, D. R., Nace, K., Giedd, J. N. and Andreason, P. (1997) 'A magnetic resonance imaging study of planum temporale asymmetry in men with developmental dyslexia', *Archives of Neurology*, 54 (12): 1481–1489.

Salmelin, R., Service, E., Kiesilä, P., Uutela, K. and Salonen, O. (1996) 'Impaired visual word processing in dyslexia revealed with magnetoencephalography', *Annals of Neurology*, 40: 157–162.

Schmolesky,M.T., Wang,Y., Hanes.D.P., Thompson, K.G., Lentgeb, S., Schall, J.P. and Leventhal, A.G. (1998) 'Signal Timing Across Macaque Visual System', *Journal of Neurophysiology*, 79 (6): 3272–3278.

Seidenberg, M. S. and McCleland, J. L. (1989) 'A distributed developmental model of word recognition and naming', *Psychological Review*, 96: 523–568.

Share, D.L. (1995) 'Phonological recoding and self-teaching: Sine qua non of reading acquisition', *Cognition*, 55 (2): 151–218.

Shaul, S. (2006) 'Investigation of Processing Synchronization between Cerebral Systems Active during Word Recognition: A Comparison of Regular and Dyslexic Readers', *Unpublished PhD Dissertation*. University of Haifa.

Shaul, S. and Breznitz, Z. (under review) 'Asynchrony of Cerebral Systems Activated during Word Recognition: A Comparison of Regular and Dyslexic Readers'.

Sousa, A., D. (2000) *How the Brain Learns*. Thousand Oaks, California: Crowin Press. Inc.

Tonnquist-Uhlen, I. (1996) 'Topography of auditory evoked long-latency potentials in children with severe language impairment: The P2 and N2 components', *Ear and Hearing*, 17 (4): 314–326.

Velay, J. L., Daffaure, V., Giraud, K.M and Habib, M. (2002) 'Interhemispheric sensorimotor integration in pointing movements: a study on dyslexic adults', *Neuropsychologia*, 40: 827–834.

Willows, D. M., Kruk, R. and Corcos, E. (1993) 'Are there differences between disabled and normal readers in their processing of visual information?', in D. M. Willows, R. S. Kruk and E. Corcos (eds), *Visual processes in reading and reading disabilities*. Hillsdale, NJ: Lawrence Erlbaum. pp. 265–285.

Wilson, G. F., Swain, C. R. and Ullsperger, P. (1998) 'ERP components elicited in response to warning stimuli: The influence of task difficulty', *Biological Psychology*, 47: 137–158.