As a result of our evolutionary history, our brains have two visual pathways. One, the key to survival, is fast and detects movement– this pathway is called the "magnocellular, or magno, pathway" (because the associated neurons are large). The other is used to discriminate details, textures, and colors; it is important for fine-grained recognition (berries in trees, patterns in faces, and so on) – this pathway is called the "parvocellular, or parvo, pathway", because the associated neurons are small.

Reading is a relatively recent cognitive innovation. Although for many of us reading feels almost effortless, we must remember that it is a very complex activity. It is not something that is innate. It is something that must be learned and practiced. Most often we think of "learning to read" in terms of learning to recognize letters, words, sounds, and the rules of punctuation. That is part of what must be learned, but, it is just a small part of what reading is all about. There is another, far more low-level or basic, type of learning that must happen for us to become proficient readers. Before we can even learn to recognize letters and words, our brains must learn how to "see" those words and letters clearly. Reading is a composite skill that employs both of our brains' visual pathways. It requires us to move our eyes (which is pretty easy) AND to interpret the information that is coming in as we do so. This information:

1. Is very fast (arrives rapidly),
2. Requires very detailed discrimination ("cat" vs "eat", "bye" vs "dye")

But it's even more complicated than just using the two pathways. In addition to needing both pathways, efficient reading requires that these two pathways work in perfect harmony. Your brain must be capable of processing rapidly changing patterns (this requires the magno pathway) that require detailed discrimination (requiring the parvo pathway). This information is arriving simultaneously and must be discriminated and interpreted both for comprehension, higher level language-based processing, and to guide subsequent eye movements.

How are Magno Problems Related to Reading?

Recent evidence from neuroscience suggests that many reading difficulties arise, not from a problem with "reading" per se, but instead from a basic problem in "seeing." Specifically, it appears that many poor readers have problems with the magno (fast) visual pathway. Although the specific cause of this deficiency remains unknown, neurobiological investigations show that children and adults with reading problems have incompletely developed magno neurons. Since these neurons are key to seeing rapidly moving things (like the letters as we read), we believe that their incomplete development hurts our ability to process fast detailed information. This manifests itself as a difficulty in isolating and identifying critical visual elements, such as letters and words, from the sea of visual features flowing onto our retinas. Poor reading is the end result. Fortunately, neurobiological research has discovered that it is actually possible to "tune" the magno pathway and thereby improve reading skills.

This tuning, called **Direction–Discrimination Training**, is accomplished by training people to see the direction that dim stripes move on varied backgrounds. This tunes the brain's neural timing, enabling the magno pathway to improve the intake of visual information. In turn, this allows the pattern-sensitive cells (the parvo pathway) to isolate and process letters and words. **Tuning the brain's pathways unlocks a child's ability to read.** Direction-discrimination training is the basis for PATH therapy, **patented in the US and worldwide**.

Half hour PATH sessions two times a week for 3 months **improve most reading skills 1-3 grade levels, increasing reading fluency two to ten fold!** PATH therapy permanently improves reading effectiveness (including fluency, comprehension, spelling, and pronunciation). Adults with reading difficulties benefit as well. The more PATH therapy is used, the more reading skills improve. PATH to Reading is a research-based program that provides a comprehensive, rapid, and effective strategy for remediating reading problems. It has been used successfully in controlled-validation studies on over 900 students in 9 different public elementary schools over the past several years. These studies, which demonstrate its effectiveness, have been published in refereed scientific journals.

In addition to helping young children and adults with reading problems, the PATH to Reading program at least doubles the field of view of older adults, improving navigation, working memory, and sequential processing (Lawton & Stephey, 2008).

Major Benefits of PATH Therapy:

1) Rapidly and effectively improves most types of reading deficits, including problems in fluency, comprehension, pronunciation and spelling.

2) Benefits are often apparent after only a few sessions.

3) These reading improvements, in turn, improve a person's self-esteem, the desire to read, the ability to understand and follow instructions, and the ability to learn. As a result, behavior often improves as well.

4) Reading is easier, more enjoyable, and requires much less effort.

5) Remediates rather than compensates.

6) Minimum frequency and duration (twice a week for 10-20 minutes) for 12 weeks to produce significant improvements in most reading skills.

7) Improvements are permanent.

8) It is much more rapid, 10 times faster, than other reading therapies

9) It improves sequential processing, and is the first training method that improves both phonological (requires accurate temporal sequencing) and orthographical (requires accurate spatial sequencing) reading deficits.

10) Direction discrimination training abates dyslexia, especially when administered when the brain is most flexible (ages 6-7 years). Interestingly, this is the same time period when children are typically taught to read.

11) PATH therapy has no medical risks.

Evidence Dyslexic Readers May Have a Magnocellular Deficit

A magnocellular (motion) deficit in poor readers (many of whom have single word coding problems, by which dyslexia is defined) is suggested by a substantial body of psychophysical evidence (Galaburda & Livingstone, 1992; Lawton, 2000, 2004, 2007; Livingstone *et al.* 1991;

Lovegrove *et al.* 1980; Ridder *et al.* 2001; Slaghuis & Ryan, 1999; Stein & Walsh, 1997; Stein 1991; Vidyasagar, 1999) as well as evidence from brain imaging studies (Eden *et al.* 1996; Demb *et al.* 1998). These findings raise the possibility that training in visual motion discrimination may lead to improvements in reading performance. Indeed, Solan *et al.* (2004) have demonstrated that a training regimen (45 minutes per week, over 12 weeks) that includes a battery of tasks emphasizing dynamic visual processing improves reading fluency in moderately impaired readers.

Results from a NIH-funded study (Lawton, 2004, 2008b) support the magnocellular deficit hypothesis since, prior to training, dyslexic readers had significantly lower contrast sensitivity, defined to be 1/(contrast threshold), for discriminating the direction of motion than did normal readers. Moreover, the NIH study demonstrated that direction-discrimination training improves both the direction sensitivity as well as the reading speed of dyslexic readers, suggesting that magnocellular deficits underlie their reading difficulties.

The 2003-2004 validation study (Lawton, 2007) evaluated an extension of the initial protocol (Lawton, 2004, 2008b) to include: 1) a more structured frame of reference that reduced background noise by also including multifrequency backgrounds (Lawton, 1985, 1989), 2) background contrasts increasing after every 3 replications from 5% up to 20% contrast to increase the activation of parvocellular neurons, 3) varying the frequency of use by having teachers determine when students were trained (see Fig. 1), and 4) longitudinal data to evaluate the resilience of the improvements in reading fluency over time (see Fig. 2).
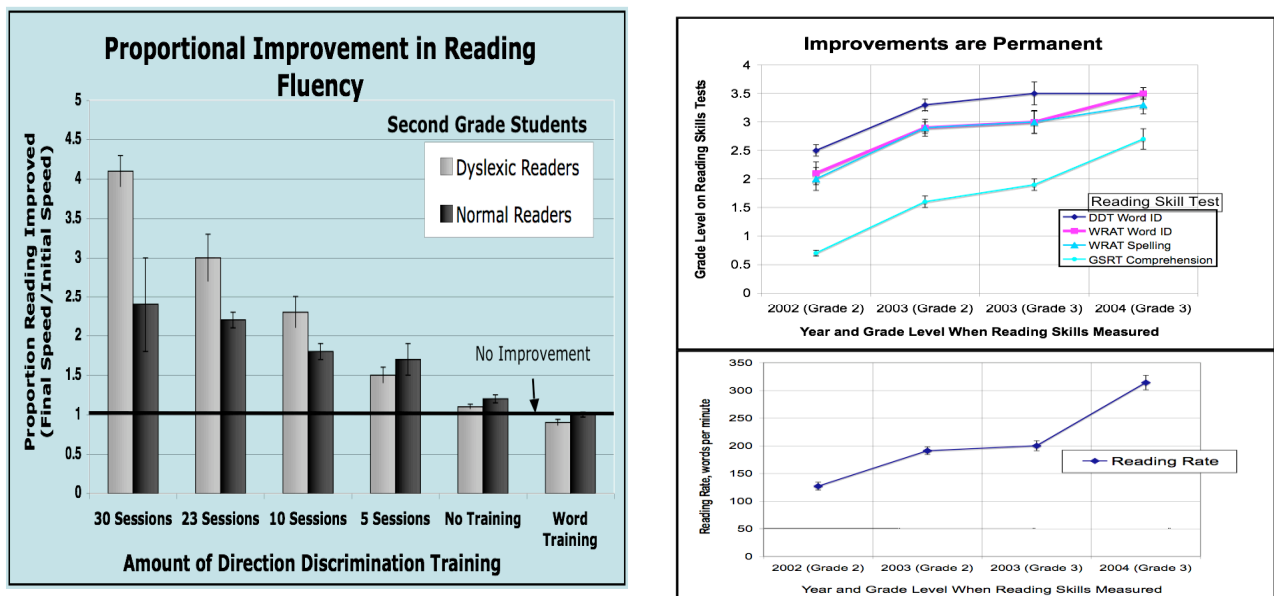

Fig. 1. Improvements in Reading Fluency 2003-2004. **Fig. 2**. Results from 6 Dyslexics from 2002-2004.

By using multifrequency backgrounds in the Direction-Discrimination Training regimen instead of only sinewave backgrounds, as done initially, not only was there a four-fold difference between the initial CSF of normal and dyslexic readers, instead of the two-fold difference found initially, but also: 1) the contrast sensitivity for direction discrimination improved significantly more (14-fold instead of 5-fold), and 2) the reading rates improved an average of four-fold instead of two-fold (Lawton, 2007). These results suggest that activating a wider range of spatial frequency channels, as ensues from using multifrequency backgrounds, provides a more robust and salient frame of reference for direction discrimination (Lawton, 1989). Our working hypothesis in this regard was that a more structured background frame of reference improves the dyslexic reader's ability to discriminate the direction of movement by widening the attention

gateway (Lawton, 2007).

Data from an initial controlled validation study (Lawton, 2004, 2008b) suggest that dyslexic readers have immature direction-selective motion pathways, since they had significantly lower direction discrimination sensitivity than do normal readers. Experience refines the output of cortical circuits by introducing patterned activity that fine-tunes the strength of neuronal connections within and among cortical columns (Trachentberg & Stryker, 2001), improving neural timing. This suggests in turn that the faulty timing of immature magnocellular neurons may be remediated by direction-discrimination training between patterns that maximally activate the motion (magnocellular) pathways, a suggestion that has been clinically validated (Lawton, 2004, 2007, 2008a,b). Results from the controlled validation studies further suggest that timing in the dorsal ('where') visual pathway is improved by training on left-right direction discrimination, enabling significant, rapid improvements in a wide range of reading skills as shown previously (Lawton, 2004, 2007, 2008a,b).

One possible neurobiological mechanism for these timing deficits is that sluggish magnocellular (motion) neurons found in the LGN and cortical areas V1 and the Medial Temporal (MT) cortex of dyslexic readers make it difficult to attend in direction discrimination tasks, since magnocellular neurons would not signal in advance of the linked pattern or parvocellular neurons (Lawton, 2004, 2007, 2008a,b). It is then reasonable to conjecture that the ability of magnocellular neurons to bracket the activity of linked parvocellular neurons over time is what has been disrupted in dyslexia, resulting in temporal and spatial sequencing deficits that slow reading speeds (Lawton, 2004, 2007, 2008a,b). Since physiological data demonstrate that magnocellular neurons control the gain of the direction-selectivity network (De Valois *et al.* 2000), perhaps the dyslexic reader's more sluggish, immature magnocellular neurons cause a deficit in attentional focus, preventing the linked parvocellular neurons from isolating and sequentially processing the relevant information needed when reading (Vidyasagar, 1999; Facoetti *et al.* 2006; Lawton, 2004, 2007, 2008a,b). This conclusion is supported by finding that only children in the direction-discrimination training group improved significantly in spelling, a task requiring sequential processing of letters, even though one of the word games (nonsense game) in the word-training group taught children to spell more easily since it required children to recognize words that were not spelled correctly.

There is some controversy about whether a magnocellular deficit underlies the reading deficits of those with dyslexia. Contrary to the magnocellular deficit theory, recent work (Sperling *et al.* 2005, 2006), suggests that dyslexic readers may suffer from a general inability to adapt their perceptual filters optimally so as to pass signal and exclude noise. These studies present evidence that dyslexic readers are relatively impaired compared to normal readers across a range of detection/discrimination tasks, provided the target is embedded in external noise, but not if the noise is absent. In this connection, it should be noted that all of the test and training stimuli used in PATH to Reading's direction discrimination training were devoid of external noise. Thus, in particular, the finding that the pre-training contrast thresholds for discriminating the direction of motion were higher for dyslexic than for normal readers argues against the noise-exclusion-deficit theory of Sperling *et al.* (2005, 2006).

Other studies that attempt to refute the contribution of magnocellular deficits to the mechanisms underlying dyslexia (Williams *et al.* 2003; Skottun, 2000; Sperling *et al.* 2003) rely upon data using either flicker detection or discrimination to diagnose those who are dyslexic. Neither sensitivity to flicker (counter-phase gratings) nor short duration patterns, as used in flicker discrimination, are optimal stimuli for activating direction-selective cells (DeValois *et al.* 2000; Baker, 1988; Pasternak, 1987). Whereas flickering stimuli are detected in the retina, direction selectivity is not detected until the cortex (Zeki, 1974). At higher levels in the motion pathways, like cortical area MT, most cells are direction selective (Albright, 1984; Van Essen *et al.* 1981). Counter-phase gratings, flickering patterns, required twice as much contrast to detect motion (Pasternak, 1987; Levinson & Sekuler, 1975), compared to sinewave gratings that moved in one

direction. Direction discrimination, not flicker discrimination, is the key dependent variable that must be measured both to detect and remediate reading deficits (Lawton, 2007). Moreover, when direction discrimination is done relative to a textured background instead of a uniform field, then the claims in earlier reports that only dysphonetic dyslexics showed magnocellular deficits (Borsting *et al.* 1996; Talcott *et. al.* 2000; Slaghuis & Ryan, 1999), are refuted by the finding (Ridder *et al.* 2001; Lawton, 2000, 2004, 2007, 2008a,b) that all types of dyslexics have a direction discrimination deficit (putatively conveyed by magnocellular neurons). When patterns that maximally activate direction selective motion pathways, located in cortical areas V1 and MT, where the background frame of reference influences the tuning of the motion-sensitive neurons (Schlack *et al.* 2007), are used in a direction discrimination task, dyslexic readers are not only detected, but their reading skills are rapidly improved (Lawton, 2004, 2007, 2008a,b). If magnocellular deficits do not underlie the reading deficits of dyslexics, it is not clear why Direction-Discrimination Training is the only type of training found to enable dyslexic readers to improve in reading fluency. Future research will focus on which cortical mechanisms underlie this remarkable improvement.

This simple direction-discrimination training regimen has been shown not only to increase direction sensitivity significantly, but also to increase the reading fluency of dyslexic readers rapidly and permanently. This training regimen makes it possible to remove a major problem faced by over 60% of the population: Not being proficient in reading, yet needing to survive in a world that is relying increasingly on the written word to convey information.

How Magnocellular Deficits Are Remediated by PATH to Reading Therapy:

Direction-discrimination training uses displays (see Fig. 3) comprising a stationary, central, "fish-like" window surrounded by a stationary, vertically oriented sine wave grating of spatial frequency $w_{background}$. The fish-like window contains a vertical test sinusoid of spatial frequency w_{test}. A given trial comprises three frames, each lasting 150, 125, 100 or 75 ms. The spatial phase of the test grating in frame 1 is $\pm45^{\circ}$, chosen randomly, relative to the cosine phase in the middle of the screen. On each of frames 2 and 3, the test grating shifts 90° in a fixed direction (either rightward or leftward), and the task of the trainee is to indicate the direction of movement using the right or left arrow key. A brief tone is presented after incorrect responses.
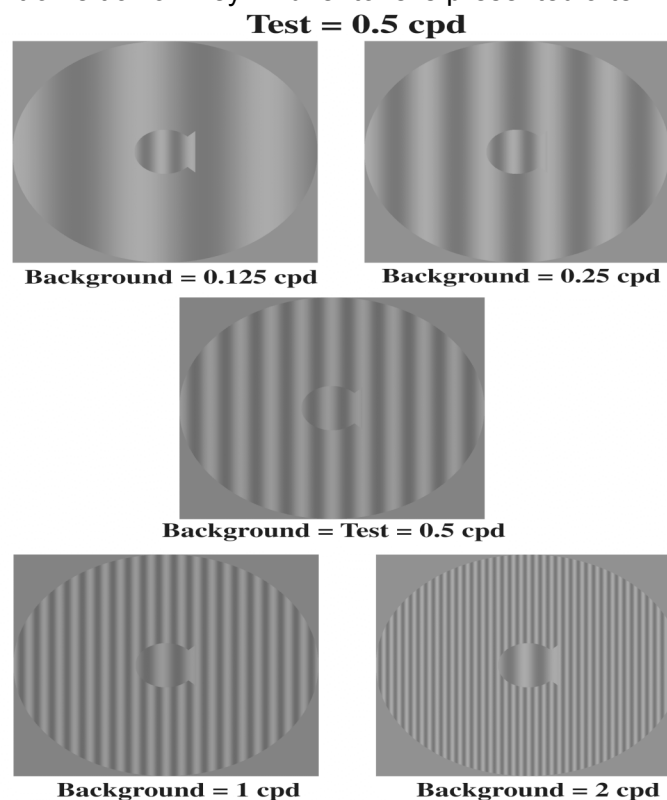

Test = 0.5 cpd

Background = 0.125 cpd   Background = 0.25 cpd

Background = Test = 0.5 cpd

Background = 1 cpd   Background = 2 cpd

Fig. 3. Sample Patterns for test frequency = 0.5 cyc/deg (cpd) on different backgrounds

The protocol for training left-right movement discrimination is:

1. Left-right direction discrimination of a sinusoidal test pattern moving relative to a sinusoidal OR a multifrequency background pattern, since multifrequency backgrounds have been shown to increase the range of discriminable patterns at very low contrasts (Lawton, 1985, 1989).

2. 5% background contrast for single and multifrequency gratings, with 10%, and 20% background contrasts for multifrequency gratings, the background contrast changing after each three replications.

3. Test pattern spatial frequencies of 0.25, 0,5, 1, and 2 cycles per degree.

4. A test pattern speed of 1.7 -3.4 Hz. The pattern moves ¼ cycle, or 90 degrees, every 150 msec – 75 msec, (this creates the perception of leftward or rightward movement).

5. Sinusoidal background patterns of different spatial frequencies, ranging from two octaves below the test pattern to two octaves about the spatial frequency of the test pattern, each background frequency being an octave apart, since neurons in the direction-selectivity network are tuned to approximately one octave (Merigan & Maunsell, 1990; De Valois *et al.* 2000).

At the start of a session, both the test and background gratings are set to 5% contrast, to ensure the pattern's contrast is in the middle of the magnocellular contrast range (Kaplan & Shapley, 1986). Each time the child correctly identifies the direction the fish stripes move, the contrast of the test grating is lowered until the child makes an incorrect response. The step size varies from 0.3% down to a step size of 0.1% at 0% contrast. Very low contrasts are obtained by special modifications to the color lookup table, varying only one color gun at a time. Although these manipulations might be expected to lead to hue heterogeneities in the stimuli, they are not visible, and moreover, it is well documented that judgments of motion direction in very low contrast stimuli depend only on luminance variations (*e.g.* Lu & Sperling, 1995). Following the first incorrect response, a double-staircase procedure (Lawton, 1984) is used to estimate the direction discrimination contrast thresholds. Three successive correct responses reduce test grating contrast by one step; each error increases the test grating contrast by one step. The staircase terminates after 6 reversals, and the mean of the last 3 is taken to estimate contrast threshold. If the last 3 reversals, where the threshold value should be leveling off, contain 4 or more increments in contrast, the threshold is considered too variable to be reliable, and the contrast threshold is automatically re-measured by the computer. Using the last 3 of 6 contrast reversals was found previously (Lawton, 1984) to provide the most reliable results compared to using larger numbers of contrast reversals. This staircase procedure estimates the contrast needed for 79% correct responses.

In a given staircase run, the center spatial frequency, w_{test}, is either 0.25, 0.5, 1, or 2 cyc/deg, and the surround grating spatial frequency, $w_{background}$, is either equal to the test frequency or 1 or 2 octaves higher or lower. A full training cycle of the left-right movement discrimination task requires 20 threshold determinations (*i.e.* one for each of the four test spatial frequencies paired with each of the five background spatial frequencies, progressing from 2 octaves below to 2 octaves above the test spatial frequency). Each session covers half a training cycle, consisting of 10 threshold determinations: one threshold for each of two 'test' frequencies displayed within each of five background frequencies. In the first session, all thresholds involving test spatial frequencies 0.5 and 1 cyc/deg are measured. In the second session, all thresholds involving test spatial frequencies 2.0 and 0.25 cyc/deg are measured. Each session takes about 8-10 minutes to complete. At the end of each staircase run, the trainee receives a score to increase motivation: The lower the contrast threshold, the higher the score.

Initially, three consecutive 150 msec time intervals are used to present leftward or rightward movement to ensure that a long duration dynamic stimulus is used and to ensure this task is easy for dyslexic readers. Even though apparent motion is used, the motion always appears smooth because of the fast speeds. Since initially the sinewave grating moves 90 deg, which is a quarter of a cycle of the spatial periodicity of the center test pattern (one-half a stripe width), in 150 msec, the speed of the test pattern has a constant temporal frequency of 1.7 cycles per second (Hz). In other words, one dark and one light stripe in the fish-like window travels almost two times across the fish body in one second. A constant temporal frequency causes the speed to appear faster for low spatial frequencies which subtend a wider spatial extent, *e.g.* test frequencies of 0.25 cyc/deg, than for higher spatial frequencies which subtend a narrower spatial extent. In a given staircase run, the center spatial frequency, w_{test}, will be either 0.25, 0.5, 1, or 2 cyc/deg, and the surround grating spatial frequency, $w_{background}$, is either equal to the test frequency or 1 or 2 octaves higher or lower. A full training cycle of the left-right direction discrimination task requires 20 threshold determinations (*i.e.* one for each of the four test spatial frequencies paired with each of the five background spatial frequencies). The stimuli used for training on left-right direction discrimination (see Figure 3) were previously found to be optimal for measuring the sensitivity of directionally-selective motion pathways (Lawton, 1984, 1985, 1989).

The procedure for determining optimal activation of directionally-selective motion pathways is as follows:

1. Sinewave gratings (activating both low and high levels in the motion pathways) are used, instead of random dots that activate only high levels in the motion pathways (Zohary *et al.* 1994). Perceptual learning is over 10-fold faster when discriminating the direction of sinewave gratings (Fiorentini & Berardi, 1981) than for random dot patterns (Ball & Sekuler, 1987).

2. The test sinewave grating moves 90 degrees (deg) between the first and second pattern interval, since this is the optimal phase difference for direction discrimination (Lawton, 1984).

3. A range of test frequencies (0.25, 0.5, 1, and 2 cyc/deg) is used to span the spatial frequencies that predominantly activate motion pathways (Kaplan & Shapley, 1986; Merigan & Maunsell, 1990; Legge, 1978).

4. A 4-octave range of clearly visible background spatial frequencies, set to 5% contrast, centered around the test spatial frequency is used to map out each channel's spatial frequency tuning function. These background frequencies are an octave apart, since neurons in the direction-selectivity network are tuned to approximately one octave (Merigan & Maunsell, 1990; De Valois *et al.* 2000), and perceptual learning of direction discrimination does not transfer to spatial frequencies differing by more than one octave (Fiorentini & Berardi, 1981). Increasing the background structure by using multiple spatial frequencies, having a low fundamental frequency, increases the contrast sensitivity of movement discrimination for a wider range of background patterns than found with single frequency backgrounds (Lawton, 1985).

5. Initially, both the test and background sinewave gratings are presented at 5% contrast, so that these patterns would be in the center of the working range of the magnocellular neurons (Kaplan & Shapley, 1986).

6. The Contrast Sensitivity Function (CSF, the inverse of the contrast threshold function) is used to evaluate a child's direction discrimination ability, since the CSF is most directly related to the output response of a directionally-selective motion cell (Albright, 1984).

7. To prevent the involvement of saccades, left-right movement is presented by having the test sinewave grating move left or right (determined randomly) in 150 msec pattern

intervals, since saccadic programming takes around 150 msec (Westheimer, 1954). This design also prevents express saccades (Carpenter, 2001) from contributing to direction discrimination.

Inventor: Dr. Teri Lawton, author of over 60 scientific papers and holder of several patents, has spent more than three decades studying the neurobiology of the visual system.. Based on her scientific work, Dr. Lawton decided to bring the knowledge she has gained out of the research lab and into the real world. After curing her first subjects (her own children) of their reading difficulties, she decided to make her training system available to a wider audience. In 1997 she founded Perception Dynamics Institute (PDI) to help those who are slow readers by using the neurobiological techniques that form the basis of PATH therapy.

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