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Neuroplasticity and Speech-Language Pathology: What it Means for Language Development and How to Apply it to Therapy

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Abstract

Research about the brain's ability to adapt and change is important for speech-language pathologists working with children with language disorders. It offers the possibility to go beyond teaching a simple skill or concept and address the brain itself. Teaching the brain new ways to process information would allow speech-language pathologists to reach the root of the problem, rather than just stopping at the surface symptoms. Research findings in neuroplasticity have important implications for how speech-language pathologists work with language disorders in preschool and school-age children, and techniques based on these findings, such as attention and music training, may produce greater results than methods that merely treat the symptoms.

Neuroplasticity and Speech Pathology: What it Means for Language Development and How to Apply it to Therapy

In recent years, there has been an explosion of popular interest in the concept of plasticity, or how the neurons of the brain can change connections based on new experiences (Hurley, 2012). Some hail plasticity as a relatively new development. In his book, *A User's Guide to the Brain,* John J. Ratey wrote, "For the first time, we are learning to see mental weaknesses as physical systems in need of training and practice. The brain is a dynamic, highly sensitive yet robust system that may adapt" (2001). Interestingly enough, the idea that the brain adapts with experience is actually an old concept, with references to it dating as far back as the early 1800's, when French physiologist Marie-Jean-Pierre Flourens spoke of the brain reorganizing itself (Doidge, 2008). In 1897, psychologist Ernest H. Lindley wrote about "the modification of the nervous system, produced by experience," and in 1914, neuroscientist Santiago Ramón y Cajal suggested the idea of plasticity in his study of neuronal behavior (Lindley, 1897; Andres-Barquin, 2001). The reason many researchers rank neuroplasticity as a recent breakthrough is that only recently have brain scientists, such as Paul Bach-y-Rita and Michael Merzenich, made practical demonstrations of the idea (Doidge, 2008). Now that these results have gained recognition, many programs, such as LearningRx and Lumosity, claim to incorporate plasticity into their therapy, calling their techniques "brain training" (Mossman, 2009). For speech-language pathologists working with language disorders in school-age children, this concept offers a new way of looking at the problem and possible solutions. Before deciding on a technique or program, however, speech-language pathologists must understand the concepts and research behind each one.

What Is Neuroplasticity?

The term "plasticity," coined by Polish psychologist and neuroscientist Jerzy Konorski in 1948, refers to the way neurons change connections and make patterns based on repeated experience (Zielinski, 2006; Ratey, 2001). When a neuron reaches a certain level of stimulation, it sends out signals to dendrites of other neurons, causing a chain reaction. Neuron chains that frequently interact with each other form patterns over time so that they can fire faster. These pattern pathways become more natural and more ingrained the more the brain uses them (Ratey, 2001).

An example of this is the musicians who make changes with their frequent practice on an instrument. Münte, Eckart, and Jäncke described a study, conducted by J. P. Keenan and colleagues, of pianists and guitarists who developed better connections between the two hemispheres of their brains because they spent so much time coordinating their hands to play (2002). They also reported the results of a similar study, which found that after only five days of piano training, the area of the brain devoted to finger movement shows greater sensitivity (2002). This is only one area where the brain adapts to repeated stimulation or repeated muscle movement, forming a new pattern or arrangement to accommodate the regular activity.

Similar changes happen for any new routine or hobby, from learning to play a sport to forming a habit (Ratey, 2001). In a study on the phantom limb phenomenon, or the continued sensation of feeling from a limb that has been amputated, V. S. Ramachandran and colleagues used magnetoencephalogram to study amputees' brains and found that the area of the cortex formerly devoted to the missing limb would eventually reroute to assist other parts of the body, such as the face (1998). Since the neuron pathways to amputees' missing limbs have fallen out of use, their brains adapt over time to focus on the areas where they currently receive stimulation.

Significance for Language Remediation

The implications of these changing patterns are groundbreaking for anyone working to correct problems with brain function, because a brain that can rewire from a missing limb or adapt to streamline piano playing could potentially improve in other areas, such as language skills. This concept, that the brain can adapt to new signals and even reroute signals from unexpected areas, allowed early proponents, such as Paul Bach-y-Rita and Michael Merzenich, to make practical advances (Doidge, 2008).

The Road to Therapeutic Application

Norman Doidge attributes the discovery of neuroplasticity of the senses to Paul Bach-y-Rita in the 1960's and 70's and describes how the idea of "sensory substitution" led Bach-y-Rita to design the concept for retinal implants (2008). Doidge discusses Bach-y-Rita's 1969 discovery that the brain can take new signals through places such as the tongue or back and substitute them for faulty signals in the eyes and balance system (2008). While his studies did not apply directly to language development, they brought plasticity out of the realm of speculation and into the area of remedial application. Bach-y-Rita's positive results made huge strides in convincing detractors of the time, though he still had to suffer through years of criticism and superiors who refused to publish his writings on plasticity (2008).

Also discussed in Doidge's book is Michael Merzenich's 1968 discovery of plasticity in adult monkeys with amputated fingers (2008). According to Doidge, Merzenich also faced hostility to his initial contributions; his supervisor discouraged him from publishing these findings and forbade him to use the word "plasticity" at all in his publications (2008). Merzenich's discovery that the brain could recycle and redirect the neurons from a missing finger to surrounding fingers went largely unrecognized by his fellow brain scientists (2008).

Merzenich, however, pressed forward with his research and, following the same path as Bach-y-Rita, used his new knowledge to bring about practical rehabilitative results, making many advances in cochlear implant technology in the 1970's and 80's (2008).

First Applications to Language Disorders

Building on his experience with hearing, Merzenich had the idea that he could apply plasticity concepts to language processing by training the brain to hear individual sounds in a word (Doidge, 2008). *Fast ForWord*, the result of his collaboration with colleagues Paula Tallal, Bill Jenkins, and Steve Miller beginning in 1997, is a computer program that slows down the sounds in speech so children's brains can more easily differentiate between them (2008). Over time, the sounds speed back up until the children have learned to listen for the blends in regular speech (2008).

Merzenich and others found that plasticity training applied particularly well to language because language development is so closely tied to experience (Ratey, 2001). Certain parts of the brain are involved in language processing, but brain scientists now consider that no one single part of the brain handles all language functioning (2001). It was previously believed that scientists would one day locate a single language center, such as Broca's or Wernicke's areas; however, the current concept of language is much more complex than this. Different parts of the brain respond to language in different ways depending on each person's experiences. Since most babies learn the basic rules and patterns of their language simply through exposure to it, each baby's brain responds to language in a slightly different way, not all of which are equally efficient. As Ratey puts it, "neither nature nor the brain always fits into discrete boxes" (2001). Fortunately, this variability of the brain also means that no response is unchangeable.

Barbara Arrowsmith Young, another innovator in neuroplasticity who has worked as a teacher and researcher in the field of school psychology, learned just how true this was as she developed exercises to retrain her struggling brain as an adult (2012). Growing up before the concept of brain training was widely known, Young had always thought her poor language skills were unfixable. As a child, she struggled with word pronunciation, spatial reasoning, awareness of where her body was in space, narrow vision span, and symbol relationships needed for math and grammar (Doidge, 2008). She wrote, "Almost universally assumed at the time was the idea that you had to play the hand you were dealt because the brain you were born with was fixed and hardwired" (Young, 2012). Her school years were difficult and frustrating, with hours spent trying to memorize concepts she could not seem to wrap her mind around (Doidge, 2008). Later, when she learned in her graduate studies that the brain can change, she designed flashcards of clocks to train her brain to process the concept of temporal relationships (2008). Because real life clocks are constantly moving, Young struggled to process them, but the flashcards gave her time to figure out the hour hand as she practiced over and over, eventually adding minute, then second hands (2008). Even though the childhood critical period for language learning had passed, Young's brain was still able to change and adapt as she gradually processed the clock pictures. After weeks of training, "not only could she read clocks faster than normal people, but she noticed improvements in her other difficulties relating to symbols and began for the first time to grasp grammar, math, and logic" (2008). These positive results led her to start the Arrowsmith School in Toronto in 1980, designing brain exercises for others with learning disabilities (2008).

Today the Arrowsmith Program focuses on retraining weak areas of the brain through computer programs and written, visual, and auditory exercises, such as studying foreign letters to improve visual memory (Doidge, 2008). The school serves children of all grade levels. Each must undergo 40 hours of testing and be diagnosed with a learning disorder before he or she is admitted (2008). In one study on all 79 students at the Arrowsmith School, representing grades 1-12, 97% of them showed improvement on tests in multiple areas, including understanding relationships between concepts, remembering detailed instructions, and understanding how words and parts of words fit together (Lancee, 2005). Testing in the area of language processing focused on such areas as vocabulary, auditory letter memory, visual letter memory, word recognition, spelling, writing in different situations, word comprehension, and passage comprehension (2005). Using techniques similar to Merzenich's slowed speech program, the Arrowsmith program allows students' brains to process areas of struggles more easily, then gradually bring them up to more difficult levels.

How Language Plasticity Training Works

According to Paula Tallal, co-director of the Center for Molecular and Behavioral Neuroscience at Rutgers University, the reason these techniques work is that a brain with a language disorder struggles to keep up with sound changes, but it can still process them in the right conditions (2002). She writes about the first experiments on sound processing time in children with language disorders, and claims she was surprised when the children were able to process slower sounds, but not normal speech sounds (2002). Based on the previous thinking that the brain was made up of fixed structures, she had assumed that the children would not be able to process sound changes under any conditions, because their specific structure for that task would be missing (2002). The fact that the children could hear slowed sounds offered a stepping stone for Merzenich's activities to gradually help many participants improve significantly in language comprehension ("All Language Skills," scilearn.com, 2013).

With modern imaging technology, people can now see exactly where brain function differs between, for example, good and poor readers. In the same way, they can also see if and how the brain changes after intervention. A recent study on fifth graders in Allegheny County, Pennsylvania, used functional magnetic resonance imaging (fMRI) to compare blood flow in the brains of 23 poor readers and 12 good readers and found that poor readers had less activation in many areas of their frontal and parietal lobes (Meyler, 2008). After a year of phonological training and reading remediation, however, they found that poor readers' brains had actually changed to show activation levels similar to the good readers' brains (2008). While visualizing and comparing brain activation differences is not feasible for every child with phonological and reading difficulties, the study supports the claim that remedial brain training can change actual brain organization.

Limits to Plasticity

Of course, neuroplasticity is not without its limits. While brain scientists now accept that neuroplastic changes can happen throughout a person's life, there is still a lot of controversy regarding which changes are limited by age and stage of development (Mahoney, n.d.). The brains of very young children are extremely active, furiously forming the connections needed to perform basic functions, such as learning to walk and speak (Ratey, 2001). This massive brain growth, while necessary at that stage in life, would be incredibly inconvenient if it continued throughout the brain's existence. Toddler brains, after all, use 225% more energy than adult brains (Wesson, 2010). The pruning and cementing processes of late childhood and puberty, though a practical necessity, do mean that the brain becomes less malleable (Lund, 2003). At this point, it becomes difficult for people to learn a second language without having an accent from their first language, as the window for language development draws to a close (2003).

Requirements That Must Be in Place

Critical periods pose potential problems for school age children with language deficits. After the critical period for language passes, areas of weakness will become more and more ingrained as their brains streamline operations. Without intervention at this point, their brain will most likely keep reinforcing the wrong pathways, since even as early as seven months, researchers have discovered that the infant's sound discrimination skills are a predictor for how well their language skills will develop later (Kuhl et al., 2005). Thus, while plasticity does offer valuable options for the clinician, it also requires work on the part of the clinician to restructure the child's experience so his or her brain will form new pathways instead of reinforcing old bad habits.

For improvement to happen, this restructuring needs to include a number of criteria. Merzenich and colleagues discovered that test subjects need to be completely focused, start at a level where they can easily succeed (i.e. with sounds slowed down so they easily discriminate between them), and receive consistent rewards for correct responses (Tallal, 2002). These conditions form an experience that the child's brain is unused to, such as hearing slowed-down words instead of regular speech. Only with this new environment in place can the researchers then gradually increase the difficulty level as the child's performance improves (2002).

Ratey describes the process from a different angle, stating the need for researchers to look at "four theaters," moving the focus from how the individual perceives the world to the individual's attention and consciousness. He traces this further to basic brain function, looking at how the brain leads to behavior output (2001). Since most treatment focuses on symptoms or output, the theaters system is an attempt to move the focus to where the weakness occurs in the brain. This allows researchers to address the problem at its source.

Criticism of Plasticity Claims

Whether or not brain training is always successful, or whether it applies to every school-aged child, is a subject of debate. Some researchers argue that brain training is an overused buzzword that can give parents false hope (Katsnelson, 2010; Owen, 2010). One study by Katsnelson of 11,430 adults between 18 and 60 found that popular computer games claiming to train the brain and improve cognitive skills did improve participants' success at the game, but had no carryover to tests on memory, reasoning, and learning (Katsnelson, 2010). While it focuses on a different population from that of school-age children with language disorders, the study does raise a valid question: whether or not improved brain functioning on structured drills will always carry over into general life skills.

In a response to the Katsnelson study and others, Hill and Serpell argue that "hasty conclusions should not be drawn," especially because the training in the study was only about four total hours, much less than that usually given in centers like LearningRx (2010). They point to several other longer studies in various school systems which have shown general cognitive improvement from the training (2010). In their 2011 results report, LearningRx revealed that children spent an average of 18 weeks in their program, and those diagnosed with a speech or language disorder saw "an average percentile gain of 24 points in IQ and cognitive skills" ("Report of LearningRx," 2011). The disparate results between these studies could very well be linked to the difference in time spent training, which would make the need for extended periods of time another limit to plasticity.

Comparing Programs and Curriculums

Numerous clinics, online programs, and curriculums promise to help rewire the brain, but there appears to be a significant lack of research on which method works best, and some would add, a lack of reliable research period. As Bree Chancellor and Anjan Chatterjee point out, "A major limitation of most research on brain fitness programs is that much of the research on cognitive software is sponsored by the companies themselves and is conducted by authors with a financial stake in the outcome of the studies reported" (2011). If speech-language pathologists and parents are to make informed decisions on brain training programs, more independent researchers must conduct studies to compare outcomes of these programs not only with one another, but also with more traditional therapy methods. Most major brain training companies serve multiple ages and functions, not catering specifically to speech-language pathology. The following is an overview of the main programs, how they work, and some of the research that has been done regarding them.

LearningRx

When LearningRx sponsored a recent study of 352 school-age children, those who had participated in a LearningRx program showed significant improvement in academics and cognitive skills compared to those who participated in no program at all (Jedlicka, 2012). Any evidence of overflow into general life skills is important, because it shows that the program really can have a positive influence on the brain. A separate 2009 study, also sponsored by LearningRx, found that students who added LearningRx to their studies showed more improvement in "Logic and Reasoning, Short-Term Memory, Word Attack, Phonemic Awareness, and Long-Term Memory" than students who participated in school activities alone (Carpenter, 2009). Those who use LearningRx attend one-on-one sessions for five to six hours a week over a period of about 18 weeks, paying $80 per hour ("Report of LearningRx", 2011). Training activities include rapid naming, rapid sequencing, and repeating patterns from memory, all catered to each student's particular problem areas (Whiteley, n.d.).

Lumosity

A less expensive option, Lumosity offers online activities for around $9.95 a month (Mossman, 2009). These also involve rapid naming, with focus on making quick decisions and switching between multiple stimuli (Katz, 2012). Unfortunately, most of the studies that have been conducted on Lumosity focus on different populations. The most applicable study to children with language disorders was one on children with Turner's syndrome and cognitive challenges, demonstrating that those "who completed the Lumosity training demonstrated significant improvements in processing speed, numeration, algebra, geometry and mental flexibility" (Hardy and Scanlon, 2009).

Fast ForWord

Fast ForWord, the brainchild of Michael Merzenich and colleagues that slows down phonemes to teach discrimination, costs about $1500 for four months. Students spend 30 to 50 minutes a day on training computer games (Mossman, 2009). Several school districts have conducted studies on the use of Fast ForWord's slowed sound programs on their students, and all agreed that it produced significant language improvements (Wahl, Robinson, & Torgesen, 2003; Woodrum, 2012). However, in a comparative study on 216 school-age children, organizers found that, while Fast ForWord did produce results, they were not any better than the results from regular language therapy (Gillam et al., 2008). This does not rule out Fast ForWord as an option, but it does bring up an important point for consideration. Until more people conduct comparative studies like this one, there is no evidence that brain training programs work better than other types of language intervention. The fact that they work in the right circumstances has achieved acceptance, but the claim that they work better than other methods remains, at least for now, unproven.

Listening and Communication Enhancement (LACE)

Of this list, LACE is perhaps the most unique because it focuses on a specific population. Targeting auditory processing and listening skills, LACE is useful for people who have been diagnosed with Central Auditory Processing Disorder (CAPD) or hearing loss. CAPD is a deficit in the way an individual processes both spoken and written language, causing struggles with listening and reading comprehension. It can have similar affects to hearing loss, but occur in an individual with normal hearing capabilities. The computer-based LACE program works by giving participants practice in increasingly difficult listening situations, from following conversations in noisy environments to distinguishing similar phonemes. In a 2011 study on 28 young adults, a group of researchers from Northwestern University found that LACE significantly improved speech sound discrimination abilities (Song et al., 2011). LACE can be accessed online by anyone, and costs $99 to download.

Table 1

Comparison of LearningRx, Lumosity, and Fast ForWord

	LearningRx	**Lumosity**	**Fast ForWord**
Areas Addressed:	--Attention --Processing speed --Memory --Logic and reasoning --Auditory processing --Visual processing --Phonemic awareness --Sensory integration	--Attention --Speed --Memory --Problem solving --Flexibility	--Phonemic awareness --Decoding --Vocabulary --Reading comprehension
Cost:	$80 per hour – recommended 18 weeks of five to six hours per week	$14.95 per month or $79.95 per year	$1500 for four months
Training Needed:	"Brain Trainers" must have college degrees and special training from LearningRx	None	2 hours of online training
Delivery Format:	One-on-one sessions at LearningRx centers, 5-6 hours a week	Online access, 20-23 minute sessions for a minimum of 3days a week	Administration by teachers through the school, 30-50 minutes a day for 4 months
Research Done:	--2012: sponsored by LearningRx, saw academic improvement in study of 352 school children (Jedlicka, 2012)	--2012: sponsored by Lumosity, saw improvement in target areas in study of 1,392 school students from 42 schools (Ng et al., 2012)	--2008: outside study, found results equal to traditional language therapy in study of 216 school children (Gillam et al., 2008)

Table 2

Comparison of Arrowsmith Program, Melodic Intonation Therapy, and LACE Program

	Arrowsmith Program	**Melodic Intonation Therapy**	**LACE**
Areas Addressed:	Sequencing, symbol relations and recognition, memory, pronunciation, auditory speech discrimination, symbolic and artifactual thinking, kinesthetic perception and speech, narrow visual span, object recognition, reasoning, motor skills	--Rhythmic aspect of speech --Vocabulary	--Auditory discrimination --Listening skills
Cost:	$3,500 per student per school year	None	$99 to download, $79 to access online
Training Needed:	One teacher from the school must undergo special training	None (basic keyboard skills recommended)	None
Delivery Format:	Administered as daily after school program by teacher at participating school	Delivered in therapy setting by music therapist or speech-language pathologist	Computer-based, completed over 11 sessions
Research Done:	--2005: study on 79 students at Arrowsmith school saw 97% improvement in target areas (Lancee, 2005)	--2006: case study found that MIT produced more lasting phrase production in client with aphasia (Wilson et al., 2006)	--2011: outside study, linked LACE to sound discrimination improvement in 28 young adults (Song et al., 2011)

Plasticity With Music

One unique area of brain training that is growing in popularity is music therapy (Thaut and McIntosh, 2010). In the aforementioned study on pianists and guitarists, the coordination required for each performer's instrument led to a more active corpus callosum, sending better communication between the two hemispheres of his or her brain (Münte, Eckart, and Jäncke, 2002). This is significant because, as Ratey explains, "Despite the asymmetry of language, more connections between the hemispheres owing to the corpus callosum may result in better language functions" (2001). Music is unique because it activates networks that are also used for other systems, such as motor control and language skills (Thaut and McIntosh, 2010). It functions as a sort of "auditory language," using the same part of the brain associated with grammar processing to detect wrong notes and changes in the melody (2010). When a person trains to play a musical instrument, the increased focus on auditory experience gradually improves the way his or her brainstem fires in response to the fundamental frequency of a sound and how well the non-primary auditory cortex encodes pitch and rhythm (Shahin, 2011.) Since these areas are also important in language processing, this can translate to an improved ability to "encode metric structure in speech" and distinguish between rapid sound changes (2011).

In the classroom, studies have shown that these crossovers from music training translate to "improved reading abilities of complex words and increased sensitivity to pitch changes in speech" (Habib and Besson, 2009). One study found a correlation between music training and increased "reading fluency" overall, perhaps due to improvements in the corpus callosum (Wandell et al., n.d.). Like Merzenich's program of slowed sounds, music improves phonological awareness by training the brain to listen for minute pitch differences in an altered environment. In this new environment, music learners must pay attention to many areas at once, including pitch, timbre, volume, rhythm, mechanics of performance, and decoding musical notation. Beyond merely attuning the brain to pitch differences, this act of focusing on and regularly practicing an instrument can also significantly improve children's attention skills and general cognitive performance (Posner and Patoine, 2009).

Using Music in Therapy

While all of the studies above focus on the simple act of learning an instrument, some speech-language pathologists and music therapists choose to utilize the plastic effects of music in more focused therapy-room settings. When a therapist chooses which form of music training to implement, they must keep the child's personality and specific needs in mind. Above all, since focus is required for plasticity to happen, the child must show an interest in the type of music that he or she will learn (Tallal, 2002). Additionally, the child must be suited to the chosen instrument or music type, and he or she must have an open attitude to learning music (Posner and Patoine, 2009).

One option is the broad array of music-related games (Habib and Besson, 2009). These can take the form of computer games or group interactive games, and can focus on either rhythmic identification, pitch discrimination, or both (2009). The game format may be especially useful for younger children or those who lack the focus to spend time on their own practicing. It also produces results: in one study, dyslexic children showed marked improvement in both phonological processing and spelling after only 15 weeks of group music games of gradually increasing difficulty (2009). Another study of children playing music computer games showed improvement in the area of phoneme-graphing mapping (2009). This improved correlation between hearing and seeing words may be related to the coordination between hearing and seeing music.

Another option, specifically focused on the rhythm aspect of speech, involves the use of singing or songlike talking. Melodic Intonation Therapy puts a word or phrase, usually two to three syllables, to a series of musical pitches (Norton et al., 2009). The interval between these varies depending on the therapist, but minor thirds are common (2009). No music training is necessary for this, but access to a piano or keyboard is helpful. The way this technique works is actually very different from the music training effects discussed above, where the left hemisphere processed the temporal component of music in the same area it processed the temporal component of language (Shahin, 2011). This technique is actually designed to target the right brain, which is the rhythm center, helping clients to visualize the words they say (Norton et al., 2009). To further this effect on the right hemisphere, therapists sometimes have children tap their left hand along with the pitches (2009).

Downsides of Music as a Therapy Method

Something important to keep in mind with music is that the brain benefits tend to happen over time, making it anything but a quick fix (Moreno et al., 2009). Many of the studies on music-driven neuroplasticity focus on students who have practiced regularly for four or more years (Moreno et al., 2009; Münte et al., 2002; Shahin, 2011). While some improvement in sound perception becomes apparent after only six months of practice, the child must keep practicing over time for benefits to become permanent (Moreno et al., 2009). Starting age also plays an important role, as researchers have discovered that music learning must begin before a child is seven to achieve full benefits (Habib and Besson, 2009). After that age, people can still learn instruments and experience brain adaptation, but their results will not be as pronounced (2009).

Benefits of Music as a Therapy Method

Incidentally, one of the same studies that found language improvement crossover from music training also found that therapists could achieve the same benefit with simple language training (Shahin, 2011). The reason some therapists choose music is not that it works better than other methods, but that music is unique in its ability to capture and hold children's interest, enriching their experience as it changes their brains (Shahin, 2011; Posner and Patoine, 2009). Even if rhythm is not the focus, as in Melodic Intonation Therapy, putting words into song form gives children a new practice format that engages their attention. Music encourages children to engage more in therapy and allows more "opportunities for repeated practice than would seem natural in non-music activities" (Geist, 2008). Repeating the same word or concept over and over as a drill can seem very dull and unnatural for a child. Shahin argues that the personalization opportunities and "emotional experience" alone make music a worthwhile therapy option, stating that "users might process sound features more efficiently when enjoying the task, for example, by selecting his/her preferred genre of music" (Shahin, 2009).

A Sample Case History

In order to illustrate the application of this information on neuroplasticity, the following is an example situation where a speech-language pathologist would use brain training programs as part of a therapy plan.

Consider the following scenario – a mother contacts a speech-language pathologist with worries over her high-schooler's ongoing struggle with grades. According to her, he claims to have difficulty with note-taking, test taking, and completing assignments on time. She is worried about his ability to succeed in college in the fall, and says that he also struggles with low self-esteem and social withdrawal. She sends the speech-language pathologists copies of reports from the past five years. One contains a diagnosis of Central Auditory Processing Disorder, which indicates normal hearing ability but trouble understanding speech. His scores on the Low Pass Filtered Speech Test and the Time-Compressed Speech Test, which are instruments to examine auditory closure and speech sound discrimination, were both below normal limits. The audiologist who performed the testing recommended educational accommodations, such as a seat near the speaker, the opportunity to take exams in private, and exemption from foreign language studies. Additionally, the audiologist recommended use of the LACE program at home to improve listening skills. After reading the reports, the speech-language pathologist asks the mother if they used the LACE program and if they saw any change. The mother remembers buying the program, and says that her son spent several months working through it and it made some change, but it had been awhile since he had picked it up again.

At this point, the speech-language pathologist considers what she knows about the LACE program. The computer-based brain training software targets listening skills in difficult situations, such as focusing on a conversation in a noisy room, or focusing on just one speaker while two people are talking. Lessons gradually increase in difficulty as the user works through the program. The speech-language pathologist has read reports confirming the success of LACE, so she can see why it made some improvement in the student's listening skills, but she also realizes that the adult-oriented program may not be very reinforcing to a high-schooler.

LACE may be unique in that it focuses specifically on listening skills, but it is not the only brain training program that may help to improve auditory processing. Lumosity, another brain training software with which the speech-language pathologist is familiar, targets a variety of areas which include attention, processing speed, memory, and flexibility. The speech-language pathologist knows that practice in these areas can also improve listening skills, and

Lumosity has the added benefit of a game-style format. She is aware that the research done on Lumosity has not been as specific to auditory processing as studies done on the LACE program were, but they do show improvement in the areas she wants to improve in her client, such as the 2011 study that showed an increase in participants' processing speed after using Lumosity (Ji et al., 2011). She remembers another study on 1,392 students where Lumosity led to both increased speed and increased memory skills (Ji et al., 2012). Based on her knowledge of the conditions where neuroplasticity works best, she decides Lumosity is a good option for this situation because it would allow the student to start at a level where he could easily succeed, present tasks in a new and different format, gradually increase in difficulty, and perhaps most importantly, use a format that might motivate him more than LACE did.

As the speech-language pathologist makes plans to meet with the student, the mother contacts her with another development. In addition to his Central Auditory Processing Disorder, the student has also been diagnosed with a hearing loss and will be fitted with hearing aids before he begins college classes and therapy. This means that he has difficulties both with the hearing component and with the processing and discrimination component of speech. Even though the hearing aids will help with his hearing, they cannot help with his auditory processing. It will also take some time for him to adjust to them. The speech-language pathologist decides to start with some hearing discrimination practice before incorporating Lumosity, focusing on the difference between words, such as "miss" and "myth," and "sue" and "shoe," and listening for key words in assignments.

In her first meeting with the student, she notes that he appears cooperative, but withdrawn, lacking enthusiasm for the sound discrimination practice. When she questions him about his transition to college, he admits that he is nervous about note-taking in the classes that do not use visual aids. While he has been open with professors about his hearing loss, he lacks confidence about requesting classroom and testing modifications. She encourages him to talk to professors and works through strategies for note-taking, asking for clarification, and showing assignments to professors ahead of time.

As she meets with the student in weekly therapy sessions, the speech-language pathologist gradually adds Lumosity training games as a therapy tool, focusing on the areas that will improve listening skills. Since she works through the lessons with him, they are able to discuss attention, memory, or speed strategies for each new game. She notices that over time, the student's attitude toward therapy gradually changes. As he progresses through the Lumosity games, he begins to show more excitement about improving his scores and frustration when he does not improve. While she initially had to remind him to check his progress each time, he now checks on his own to see which areas he needs to earn more points in. When she asks the student about his overall impressions, he claims that the Lumosity helps him a lot more than the LACE did.

The key to Lumosity's success with this student is the motivation factor. To a college student, LACE seems more like homework, while Lumosity activities, such as "Pinball Recall" and "Top Chimp," seem more like video games. Both programs have evidence behind their potential to change the brain, and neither program was the only option the speech-language pathologist had, but Lumosity offered unique opportunities for neuroplasticity in its ability to motivate the student. The speech-language pathologist chose Lumosity based on her knowledge of how neuroplasticity works.

Now, fast forward a year in the student's college experience and his confidence has increased both in communicating with professors and asking for clarification in conversation.

While he is still withdrawn, he now greets the speech-language pathologist spontaneously and makes observations about the day's assignments. Through pragmatics activities, such as discussing what questions he would ask as an interviewer or discussing what emotions people display in different pictures, he has improved his social awareness. When he works through Lumosity assignments, he is excited to see which new games he has earned for that day, and works hard to make progress.

The speech-language pathologist knows that Lumosity was not some miracle program that made an overnight change in the student. It was a tool that, in combination with other tools, made a difference in the way the student's brain processed auditory information. She did not expect a sudden fix or a dramatic brain improvement, but relied on the evidence she had read that forcing the brain to process information in a new way over time can improve processing in that area. She also did not have a chosen program that she applied to all clients. In the case of this student, she carefully considered his history, needs, and interests before choosing a program that would best set up the conditions for his brain to change. Brain training must always be unique to the individual, because only when the conditions are right for that individual will brain training occur.

Conclusion

The realm of plasticity training for speech-language pathology is still a relatively new and unexplored one. Its allures and possibilities are many, its limits not yet fully understood. While plasticity may not be a recent discovery, attempts to harness its principles for brain remediation are still in the early stages of research. It is important to balance claims of plasticity's potential with actual research on whether or not plasticity is effective under specific circumstances. Those who have studied brain training bring valuable information to the table: that the brain can indeed change under certain conditions. Unfortunately, the best way to bring this about is still unclear. Numerous programs attempt to capitalize on the brain's plasticity, among them centers like LearningRx and online programs like Lumosity and Fast ForWord. In its own way, music training offers to improve the brain while providing emotional and cultural experience. Before plasticity can be of real use in treating language disorders, however, more research must compare the effects of different programs on children with language disorders and the effects of brain training with other forms of language therapy. Only with this data in hand can speech-language pathologists confidently step forward into this new realm of "brain training."

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