Good for the soul, good for the brain: The positive educational neuroscience perspective

Historically, there have been many assumptions made about the effects of brain damage. Recently, science has begun to challenge many of these ideas and, in some cases, shown them to be wrong.

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Executive summary

- The traditional view of research on the brain has focused on impairment, following a *lesion-deficit model*.
- *Positive educational neuroscience* (PEN) is a new approach that explores how learning practices lead to neuroplastic changes that have the potential to enhance neurocognitive flexibility through overcompensation.
- An example of overcompensation is how the brains of children who are born blind are reorganized so that visual cortical areas are used to enhance tactile processing, in addition to the sensorimotor areas.
- Another example is that socially-based music programs have the potential to enhance positive changes in the brain that lead to enhanced integration, or neurocognitive flexibility, across brain areas.
- Teachers are encouraged to support positive changes and inclusive environments by incorporating haptics into art classes, and to provide all students the opportunity to learn music in social collaborative settings.
- One of the chief reasons for the success for PEN-inspired educational and intervention programs is that they promote a social collaborative learning environment. Child/youth empowerment, ownership, and peer support are fundamental components of their curricular design.

Introduction

This brief has three goals: (1) to give an overview of a positive educational neuroscience (in short, PEN); (2) to show how PEN links to the concept of neurocognitive flexibility; and (3) to provide examples of how the present concept of neurocognitive flexibility can be used for education.

Positive neuroscience

Brain impairment has been the classic topic of much of neuroscience research. From this *lesion-deficit* perspective, the goal is to study loss of ability and function in the brain. That is, how damage to the brain can negatively affect behavior—and so understand the brain-behavior link. It is usually argued that damage to the brain such as a lesion will always lead to a loss of function; that a second lesion will always worsen the effects of the first lesion; that a loss in sensory processing (e.g., blindness, deafness, etc.) will usually lead to impairment; and that aging is always associated with functional deficits. These ideas, however, appear in some cases to be wrong. Although this approach has contributed a lot to our understanding of the organization of function in the human brain, it has its drawbacks. By focusing on the negative effects of changes in the brain, the lesion-deficit perspective can overlook positive changes that stem from *neuroplasticity*. The brain may undergo compensatory changes leading to adaptive strategies, which may assist in coping with disease and restoring function.

There are many examples that question the traditional view that damage to the nervous system inevitably leads only to impairment and a loss in performance. In developmental neuropsychology, there has also been a greater recognition of the occurrence of enhanced function in conditions such as autism (Frith & Happé, 2009) and dyslexia (Schneps et al., 2012). Overall consideration of the effects of brain disorders reveals that there may be three forms of beneficial (*positive*) effects: (1) Enhanced performance compared with neurologically intact individuals ("lesion facilitation"). This occurs, for example, in some amnesic patients (i.e., suffering memory losses). They are better than individuals without amnesia in un-learning or ignoring distracting information during a task in which what to learn changes from moment to moment. (2) Alleviation or restoration to normal following a second brain lesion ("double-hit recovery"). This is usually described in cartoons as when someone changes their personality following a bang to the head, only to recover miraculously after a second bump. Although cartoons exaggerate, there are a few well-documented cases that show something similar, in that subsequent different lesion may ameliorate deficits caused by the first. (3) Direct or indirect benefit for long-term neurological outcome after specific cognitive impairments ("paradoxical positive outcome") (Kapur et al., 2012). For example, this is the case of individuals who are blind and show superior performance in tactile and auditory perceptual tasks. Similarly, individuals with deafness can develop superior cognitive skills for some tactile and visual tasks.

In sum, positive neuroscience emphasizes the importance of looking at change rather than simply focusing on shortfalls. This is similar to the perspective used in the fields of positive psychology and positive clinical psychology. The emphasis is on optimism, flourishing, resilience, and ways of coping with impairment (Seligman & Csikszentmihalyi 2000). The emerging fields of "positive neurology" and "positive neuropsychology" have a similar focus, by placing greater attention on concepts such as resilience over the past few years. These fields emphasize what individuals can do by exploring past strengths and interests in relation to intact skills. Another central focus involves examining how home, social, and work environments can be altered to support these skills and talents. Furthermore, rehabilitation efforts are also encouraged to support recovery through empowerment.

From clinics to classrooms: Positive educational neuroscience (PEN)

> *"The doctrine of overcompensation has an important significance and serves as a psychological basis for the theory and practice of educating a child with a loss of hearing, sight, and so forth. What horizons will open up to the pedagogue, when he recognizes that a 'defect' is not only a minus, a deficit, or a weakness but also a plus, a source of strength and that it has some positive implications!"* (Vygotsky 1929 as re-edited in Vygotsky, Rieber and Carton, 1993, p. 29).

The above quote by the well-known developmental and educational psychologist Lev Vygotsky clearly expresses the role of compensation and plasticity in children with physical and learning disabilities. These ideas make contact with the sociocultural approach to education and teaching. It is important to note that Vygotsky's idea of overcompensation is a broad one and does not solely apply to disability. It is about strengths arising from weaknesses and abilities arising from deficiencies across all human development.

Vygotsky drew from a number of examples: vaccines that transform a child's sickness into superior health; white blood cells that rush in greater quantity to the infected area than is needed; the organ (e.g., a lung, a kidney) that takes over the function of another damaged organ and develops into full function of both, etc. He explained that the feeling or consciousness of inferiority caused by impairment becomes the primary driving force for overcompensation leading to superior health and well-being. To support this claim, Vygotsky cited a few examples of historical figures recognized for their resilience and gifts stemming from overcompensation, including: Ludwig van Beethoven, the famous German pianist and composer who continued to compose exquisite pieces of music despite gradual hearing loss leading to deafness; and Helen Keller, the American humanitarian who experienced early deafness and blindness yet succeeded at completing college and advocating for others through her lectures and writings.

To ensure that overcompensation from psychological awareness was not to be confused with the biological theory of organic compensation or the theory of the substitution of sensory functions, Vygotsky discussed the case of blindness, "in a blind child we are dealing not with the possibilities of sight being automatically replaced but with the difficulties arising from its absence. These difficulties are resolved by the development of a psychological superstructure" (Vygotsky, Rieber and Carton 1993, p. 59). It is important to note that the ideas of "consciousness" and "psychological superstructure" for Vygotsky were synonymous with what today we call *executive functions* mostly dependent on the frontal and prefrontal areas of the brain (See Luria, 1973, for a clear translation of Vygotsky's ideas in terms of modern neuropsychology). Therefore, the idea of overcompensation coincides to what today is called *cognitive* or *neurocognitive flexibility*—that is, the mental ability to adjust thinking or attention in response to a changing situation, be it rules of a task, information in the environment, or goals of the individual.

To engage in actions that stem from neurocognitive flexibility, we must be consciously aware of our control over them. We need to be aware of the variety of options for the particular situation to plan ahead, organize our thoughts, and make use of what we remember from similar situations. Similar to what was proposed by Vygotsky, it then can be argued that neurocognitive flexibility requires an advanced aspect of human consciousness. That is, the understanding and awareness of possible options and alternatives simultaneously within a given situation. This permits better planning, organization, and use of memory. Studies using neuroimaging methods have revealed a network of brain areas that work together and are associated with neurocognitive flexibility. The network includes the prefrontal cortex, basal ganglia, anterior cingulate cortex, and posterior parietal cortex.

Neurocognitive flexibility and overcompensation can be combined in an emerging subfield known as positive educational neuroscience (PEN, Hedayati & D'Angiulli, 2016; Hedayati, Schibli & D'Angiulli, 2016). The main idea is that the most general aspect shared by all definitions of flexibility is that *mental practices which we believe are "good" for us and have a positive impact on us also have a positive influence on our brain and neurocognitive functions*. To say it with a pun, good for the soul, good for the brain! (D'Angiulli, 2016). Positive educational neuroscience attempts to describe these influences in terms of outcomes on the brain, mind, and well-being of learners. That is, PEN is an attempt to find out which learning practices are "good" for the brain by explaining the responsible mechanisms. It is important to clarify that good does not mean effortless or easy. Also, the changes in the brain that correspond to various learning practices (neuroplasticity) are not necessarily of the same type and may not have aspects in common in every case. These could be changes uniquely associated with a specific practice.

The following two examples of learning practices related to different educational settings describe how neuroplasticity can lead to positive outcomes: (1) learning to draw in congenitally totally blind children, and (2) music training in children from disadvantaged neighbourhoods.

Examples of positive neurocognitive practices

Drawing without seeing: Drawing in children who are completely blind from birth

You are probably wondering, "How can children who are completely blind from birth draw?" Much like braille, there are materials, such as Mylar plastic sheets, that allow children to draw with a resulting raised line that they can touch, referred to as *haptic drawing*. (Haptic stands for tactile or touch sensation plus movement orienting the touch sensory receptors in the skin). The ability to perceive through haptics increases naturally throughout development, as we age our ability to discriminate and identify tactile aspects of objects improves. However, research on blind and blindfolded sighted children has shown that blind children are better at haptic picture recognition and touch exploration (Pathak & Pring, 1989). Of interest, when blindfolded sighted children were guided on how to explore through touch in order to identify the desired image, their performance improved dramatically to the point that was equal to that of blind children (D'Angiulli, Kennedy & Heller, 1998). What does this suggest? Guidance and practice improves performance.

Development in haptic drawing has been shown to improve when children are given the opportunity to practice with the necessary materials. If provided with the appropriate tools and time to practice, ability in haptic drawing follows a similar progression as visual drawing: from scribbles and basic forms to more complex abstract images. Following this notion, we explored haptic drawing ability of blind children over the course of nine months and discovered improvement and more competence over time. Furthermore, children produced fewer pictures over time while the quality of the pictures increased in terms of complexity and detail (D'Angiulli, Miller & Callaghan, 2008). Despite not being able to see, these children clearly illustrated elements of visual art such as perspective (see Figure 1) and, even more surprising, pictures demonstrating movement (see Figure 2).

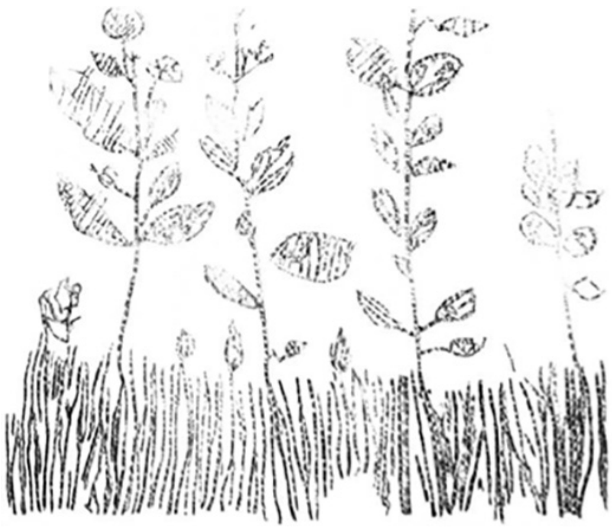

Figure 1. "Field" by a 12-year-old early blind boy.

Figure 2. "Ball bouncing away" by a 12-year-old congenitally blind child.

How can this be explained? From the perspective of positive educational neuroscience, blind children engage parts of the brain that are typically used for vision through *cross-modal plasticity* to enhance tactile processing.

We often think of vision as the only way to perceive pictures, but it seems that the brain can adapt itself to rely on spatial representations of touch through long-term memory when necessary. Children who are born blind or experience blindness early in development reorganize their brains so that visual cortical areas are used to enhance tactile processing, in addition to the sensorimotor areas. In this sense, the brain is *overcompensating* for the child's inability to see by improving the child's sense of touch, which seems responsible for refined perceptual learning and memory. This is supported by research showing that blind children have improved memory for haptic drawings in comparison to sighted children (D'Angiulli & Waraich, 2002). Neuroimaging studies using functional magnetic resonance imaging (fMRI) have shown that the occipital cortex, which is typically associated with visual processing, is also engaged during object recognition through touch (Zangaladze et al., 1999). The bottom line: Blind children are not at a disadvantage when it comes to picture perception or drawing due to *neurocognitive flexibility* if given the opportunity to practice these skills through touch.

Drawing without seeing: Implications for educators

It is evident that incorporating haptic drawing and other materials that rely on touch into the classroom would clearly benefit children who are blind as it appeals to their neurocognitive skills and enhances their ability to perceive and understand their environment. But what about children who see? Is there any benefit for them? And what about children with vision impairment, or low vision? The short answer to all of these questions is: Yes. To demonstrate the potential benefits, we have captured the process in the flow chart below (Kirby & D'Angiulli, 2011).

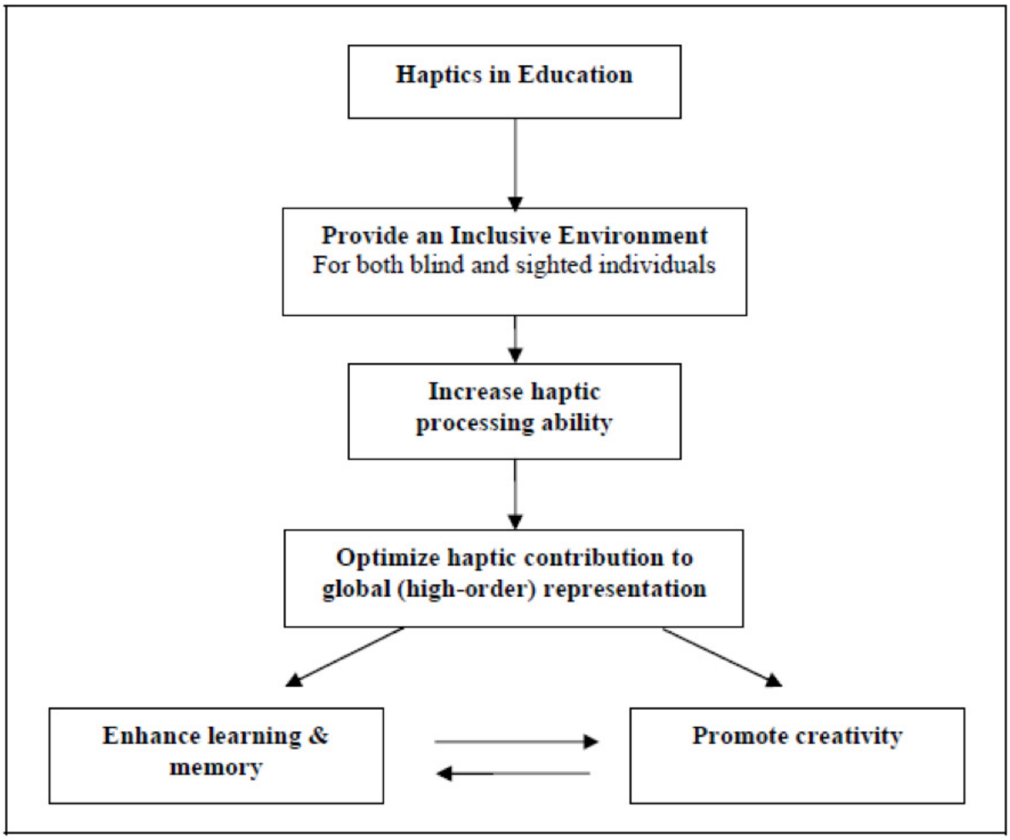

Figure 3. Haptics in education (Kirby & D'Angiulli, 2011).

First and foremost, incorporating haptics in education promotes a more inclusive environment. Blind children will feel more accepted in the classroom as sighted children will have a deeper understanding and respect for tactile processing. Children can be encouraged to improve their ability to process tactile information through the use of haptic drawing. Elements of art such as figure-ground relationships can be taught through tactile activities. For example, children can be asked to create a textured collage then to touch the finished product and draw the figure-ground relationships. Such activities would enhance children's haptic processing ability, which is especially important for children with low-vision.

Research has demonstrated that low-vision children when blindfolded are the most disadvantaged when it comes to replicating complex haptic pictures in comparison to blind and blindfolded sighted children. It is believed that blind children induce a tactile representation from memory whereas sighted children rely on a visual representation to copy the picture; both approaches led to success as children were engaging perceptual skills that came easily to them. However, children with low-vision may have relied too heavily on visual processing when attempting to create an image in their mind to replicate. It is possible that more emphasis on tactile processing would lead to cross-modal plasticity for low-vision children which may enhance their perceptual skills (Bouaziz & Magnan, 2007). An example of an activity that could be easily adapted into the classroom is to have children guess (blindfolded) what the implied shape is on a ready-made collage, such as three strands of spaghetti suggesting a triangle without the ends touching.

Furthermore, applying haptic processes has been found to facilitate the encoding and memorization of information and concepts, such as letter recognition required for reading (Bara, Gentaz, Cole, Sprenger-Charolles, 2004). Letter cutouts that allow children to touch and identify the shape of letters may enhance memory and recognition and also includes participation from blind students. Sighted children may also take an interest in learning braille alongside their blind classmates, further enhancing inclusion and promoting neurocognitive flexibility.

Finally, using more of our senses and integrating information may enhance creative expression. Providing children with materials that support exploration of multiple senses will broaden their understanding and support cross-modal plasticity in students with and without visual impairments.

"Tuning in" the developing brain: Music training enhances integration of brain areas

We can all relate to the power of music for influencing how we feel. Parents have also recognized music's potential for influencing their child's well-being, and have used it in various ways. Parents of children aged 3-8 years have expressed using music strategically to calm down their children, to alleviate boredom, to promote feelings of happiness and excitement, and to promote fantasy imagery (Saarikallio, 2009). Emotional and reward brain circuitry can be activated through musical involvement, and these changes in the brain, or *neuroplasticity*, may lead to lasting beneficial effects.

Music's influence can be observed at various levels. At the brain level, it affects the brain's structure and function. At the mind level, it affects cognitive processing. At the personal level, it can influence one's thoughts and emotions and the regulation of well-being. At the social level, music enhances social cohesion (Wilson, 2013). Additionally, many systems are engaged through music making, displayed in Table 1.

Table 1: Systems engaged through music making

Sensory processing	Auditory, visual, tactile, kinesthetic
Auditory perception	Auditory recognition, pitch perception
Learning fine motor skill	Coordination of both hands, control of digits and voice
Integration of sensory motor modalities	Monitoring and correcting during performance
Visual and spatial processing	Visuospatial perception, mental rotation
Executive function and attention	Auditory and spatial working memory and imagery, selective and maintained attention
Processing of emotions	Emotional awareness and expression, anticipating and experiencing reward
Processing of memory	Procedural, semantic, and episodic memory
Social cognition	Empathy and imitation, theory of mind

Adapted from Wilson (2013)

The positive influence of learning to play a musical instrument during childhood has been documented across many skill sets; however, only recently has the collective influence of music training with children from lower-socioeconomic (SES) backgrounds been explored in developmental neuroscience research. Following the positive educational neuroscience approach, our research demonstrates that social musical intervention programs, like El Sistema, enhance children's neurocognitive flexibility which may, consequently, improve well-being. El Sistema is a worldwide musical intervention program that originated in Venezuela and targets children growing up in poverty by giving them the chance to be involved in an ensemble orchestra group. This social learning environment has the potential to promote resilience and empower children by focusing on positive changes.

OrKidstra is one of many music programs that have been inspired by El Sistema in Venezuela. Run by The Leading Note Foundation (LNF) in the Ottawa region, OrKidstra provides children from disadvantaged communities the opportunity to learn to play a musical instrument in an orchestral ensemble. The program is offered to all children between the ages of 5-16 years regardless of income status, however cost is determined based on a family's earnings. For families who cannot afford to pay, the program is free (85% of the children enrolled). The philosophy of the program is centered on promoting cooperation and mutual respect as children build their confidence and learn to play in a group. One of the main goals of the program is to create a sense of community for families and children from diverse backgrounds, and to promote the value of music. There is an emphasis on music being the key to social change and to improve the lives of children dealing with challenging life circumstances.

We discovered that children participating in OrKidstra showed differences in brain activity when compared with other children while completing an auditory attention and impulse control task. Using electroencephalography (EEG), which is a neuroimaging technique that monitors electrical brain activity, we discovered that these children showed enhanced neurocognitive flexibility in areas that correspond with executive functions (frontal and central areas of the brain). We analyzed the timing of these changes in relation to the task using a method called event-related potentials (ERP) analysis. We found that the timing of increased coordination and shared distribution of the brain activity suggests that children involved with OrKidstra have a heightened level of appraisal or awareness for completing the sound-based attention task (i.e., Post-300), especially in response to a tone of a higher pitch (2000Hz), shown in Figure 4 (Hedayati, Schibli, & D'Angiulli, 2016).

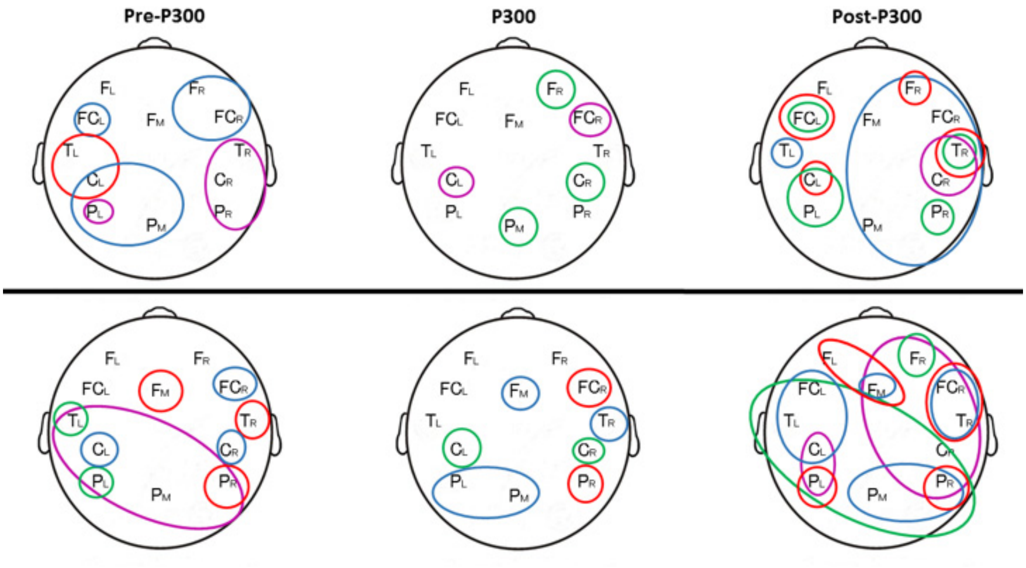

Figure 4. Patterns of electrical brain activation associated with musical training. For a detailed description see text. (Adapted from Hedayati, N., D'Angiulli, A. & Schibli, K., 2016.)

First of all, Figure 4 shows a top view of the head, and the positions of the electrodes which capture electrical brain activity (F = frontal, C = central, T = temporal, P = parietal). The figure shows the differences in brain activity between the two groups of children, those in OrKidstra and those that were not. In this example, the children were asked to press a button in response to a tone at 2000Hz (*top panel*), and to withhold their response to the tone at 2000Hz (*bottom panel*). The first column shows the differences in early brain activity (Pre-P300), the second shows the differences in brain activity 300ms after hearing the sound (P300)—which is associated with identification, and the third shows the difference in late brain activity (Post-P300)—which is associated with appraisal and awareness of the sound. Round coloured circles/ovals represent the different significance levels for the ERP differences, purple showing the greatest difference, then green, then blue, and lastly red (the least amount of difference).

So you're probably wondering, what on earth do these pretty pictures mean when it comes to children's learning? The take-home message: Socially-based music programs have the potential to enhance positive changes in the brain that lead to enhanced integration, or neurocognitive flexibility, across brain areas. This enhanced "global-sharing" of the brain results in increased awareness and attention. Furthermore, programs that are developed with cooperation and inclusivity in mind focus on children's strengths and promote resilience.

"Tuning in" the developing brain: Implications for educators

Music programs like El Sistema can have beneficial effects on children's well-being by influencing their brain circuitry leading to positive outcomes such as enhanced neurocognitive flexibility. This would suggest that music learning is an important aspect of a child's education. More importantly, learning to play an instrument is often done through private music lessons which many families cannot afford. This is a concern considering learning to play a musical instrument has been linked with increased self-esteem (Costa-Giomi, 2004) and, as we have shown, enhanced neurocognitive flexibility in children from disadvantaged backgrounds. This opportunity should be available to all children. It is important to note here that learning music may not appeal to everyone, and this will prevent any positive changes from taking place—children need to be given the choice through early exposure whether learning to play an instrument is important to them.

El Sistema has a few underlying themes: (1) It is accessible; (2) The musical training is regular and intense; (3) Collective courses are provided and practice is done in an ensemble social setting; and (4) Quality musical production is pursued (Majno, 2012). Being involved in such a program requires motivation and commitment from children, not to mention the music instructors. If we are to seriously consider "Music" as a core subject in schools, then it should be taught by teachers with musical experience, preferably expert musicians. Too often, general teachers are expected to teach classes in the arts with limited support, especially in the younger grades. Although some exposure is better than none, the best outcomes will come from collaboration between professionals in the field and generalist teachers.

All the observations and findings suggest that the chief reason for success for El Sistema and El Sistema-inspired programs are that they promote a social collaborative learning environment. Child/youth empowerment, ownership, and peer support are fundamental components of the El Sistema philosophy. Children teach other children, and ensemble playing is emphasized from the outset. A plausible hypothesis of the mechanism through which El Sistema may achieve its success may be in getting "under the skin" by strengthening the reciprocal social relationships or bonds at the level of the neural substrates underlying socioemotional, motivational, and self-regulatory well-being of the apprentices. This is achieved through engagement in cooperative learning experiences, which are rewarding, creative, and self-expressive. Such core experiences, with their neural correlates, are then "learned" by the adults gravitating around the children. According to this neurosociocultural account, children become the vehicle to a culture of collective productivity grounded on hard work and respect for each other, and they create spontaneous networks of social capital around them, switching from competitive to cooperative citizenship.

Finally, the integration of brain regions that are activated during music learning also contributes to literacy and language. We have described how learning music improves executive function skills such as attention, impulse control, and memory which are essential for understanding language and learning to read. Music can promote a socially inclusive environment for children learning English (or whatever the dominant language is in a particular region) as a second language and children with dyslexia. The advantages of music training have already been evidenced to support phonological processing for children with dyslexia (Forgeard, 2008).

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