THE IMPACTS OF LEARNING TO READ ON BRAIN ACTIVITY AND A SOCIOCULTURAL VIEW ON HUMAN COGNITION: A POSSIBLE RELATION

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Abstract: the present paper has a threefold objective: (i) to present a sociocultural view on human cognition; (ii) to review studies on the impacts of learning to read on brain activity; and (iii) to draw a parallel between a Vygotskian view on human cognition and neuroscientific evidence about the changes that take place in human brain activity as we learn to read. The reviewed studies show how learning to read changes brain activity, as well as how the brain reorganizes itself in order to accommodate new functions as a response to this process. From a Vygotskian stance, this illustrates how human cognitive development is fostered on the external plane, as we interact with socioculturally constructed artifacts.
Keywords: Human cognition. Sociocultural Theory. Reading. Brain activity.

OS IMPACTOS DO PROCESSO DE APRENDER A LER NA ATIVIDADE CEREBRAL E UMA PERSPECTIVA SOCIOCULTURAL DA COGNIÇÃO HUMANA: UMA RELAÇÃO POSSÍVEL

Resumo: o presente trabalho visa: (i) apresentar uma perspectiva sociocultural sobre a cognição humana; (ii) revisar estudos sobre os impactos do processo de aprender a ler na atividade cerebral; e (iii) fazer um paralelo entre uma perspectiva Vygotskiana sobre a cognição humana e evidências da neurociência sobre as mudanças provocadas na atividade cerebral humana ao aprendermos a ler. Os estudos revisados mostram como aprender a ler muda a atividade cerebral, bem como as maneiras com que o cérebro acomoda novas funções em resposta a esse processo. Partindo de uma perspectiva Vygotskiana, ilustra-se como o desenvolvimento da cognição humana é impulsionado no plano externo, ao interagirmos com artefatos socioculturalmente construídos.
Palavras-chave: Cognição humana. Teoria sociocultural. Leitura. Atividade cerebral.

Introduction

In spite of the different assumptions regarding the relation between language and human psychological development, there is consensus that these two aspects are, somehow, linked. Among the different views on this intriguing issue, Lev Semyonovich Vygotsky's (1896-1934) stands out for highlighting and explaining the way language — a socially constructed psychological artifact — fosters the organization of human cognition (VYGOTSKY, 1978, 1987). Although this perspective does not neglect human biological

attributes, Vygotsky's focus lies heavily on sociocultural aspects so as to explain the aforementioned relation. In this vein, bringing into discussion studies that have investigated the way the human brain responds to language may lead to further exploration of the connection between this culturally constructed means[1] and human cognition.

In this context, neuroscience studies have shown that learning to read impacts brain activity, leading to the development of a neural basis to reading (TURKELTAUB *et al.*, 2003), fostering functional reorganization processes in the brain (SKEIDE *et al.*, 2017), enhancing brain responses (DEHAENE *et al.*, 2010), among other changes in the organ that seem to have resulted from learning to read. Moreover, one of the most important discoveries in Dehaene *et al*.'s (2010) study was the relationship between the visual word form area (VWFA) and reading, as well as how brain responses to reading acquisition signal a connection between oral and written speech, as it is going to be further explained in this paper. Therefore, it seems like learning to read, a "profound cultural experience" (SKEIDE *et al*., 2017, p. 1), does impact brain functioning.

With all of the above in mind, the present paper has a threefold objective: (i) to present a sociocultural view on human cognition; (ii) to review studies on the impacts of learning to read on brain activity; and (iii) to draw a parallel between a Vygotskian view on human cognition and neuroscientific evidence about the changes that take place in human brain activity as we learn to read.

After having the paper's main rationale and objectives presented, the discussion that follows is divided into four sections: *A sociocultural stance on human cognition,* in which Vygotsky's main ideas on the issue are explored; *Learning to read and the human brain*, in which studies that approach the way learning to read impacts brain activity are reviewed; *Human cognition and reading as a culturally constructed means: building bridges between a sociocultural view and neuroscience studies*, in which an attempt to draw a parallel between Vygotsky's view on human cognition and neuroscientific evidence of how learning to read may lead to changes in brain activity is made; and *Final remarks*, in which the paper's main points are resumed, as well as possible future directions are given.

1 A sociocultural stance on human cognition

According to Vygotsky (1978; 1987), it is the very participation in sociocultural activities that propels human cognitive development. Briefly speaking, people interact with the world around them (*i.e.* other people and objects) and, as interaction develops, they internalize the knowledge they need so as to deliberately operate in the world. In other words, the Vygotskian approach understands that every human higher mental function — the ones we have voluntary control over (*e.g.* conceptual thinking, logical reasoning, voluntary attention etc.) — appears twice: first, on the external plane, when people interact with the world around them; and, later on, on the internal plane, within the individual, which indicates cognitive development (OLIVEIRA, 2001). An important aspect of this movement is that it is, in its essence, a mediated one, therefore, indirect: it happens primarily through people's engagement with culturally constructed auxiliary means (*e.g.* language, concepts etc.).

When explaining this process of internalization, Vygotsky (1987) states that language is the most pervasive means that allows it to happen, since it is through language that people both communicate and make sense of the world. The author's view on human psychological development claims for a twofold function of human language: (i) it is used for social interaction; and (ii) it organizes human thinking (LANTOLF; THORNE, 2006). As regards this second function, Vygotsky (1987) believes that it is language that fosters the development of higher forms of human thinking. The author goes on and states that this development is only possible because these higher mental functions are anchored on elementary ones, these being biologically endowed. In other words, for human cognitive development to take place, higher mental functions depend on elementary ones, which are innate. In the words of Wertsch (1985), Vygotsky claimed that "Natural development produces functions in their elementary forms, whereas cultural development converts elementary into higher mental processes" (WERTSCH, 1985, p. 24). Therefore, although Vygotsky's work heavily focused on the role of sociocultural aspects in human development, he did acknowledge the paramount importance of elementary functions in this process.

What Vygotsky called elementary mental functions are those which children carry with them at birth. These innate mental functions include, for example, sensory memories, which allow the child to perceive the world through the senses of touch, sight, hearing, smell, and taste; also reactive attention to the input she receives from the environment; among others. Higher mental functions, on the other hand, such as voluntary attention and concept formation, for example, are gradually acquired as a result of an individual's interaction in the world. Elementary mental functions, therefore, are unconscious and involuntary, and part of what Vygotsky called "the natural line of development", whereas higher mental functions are conscious and voluntary actions under the control of the individual and called "the cultural line of development" by Vygotsky (FERNYHOUGH, 1996).

According to Woolfolk (2016), the changes that occur during an individual's development are the result of two different processes: maturation (also called nature) and interaction with environment (also called nurture). As she puts it, changes due to maturation, for example, physical growth, are genetically programmed, and "relatively unaffected by the environment, except in cases of malnutrition or severe illness" (WOOLFOLK, 2016, p. 58), whereas other changes that arise from learning, for example, result from an individual's interaction with the environment and are part of his/her social development. As far as we are concerned, a connection can be made here between the concept of maturation (*i.e.* nature) and what Vygotsky called "the natural line of development", and also between the interaction with the environment (*i.e.* nurture) and his "cultural line of development".

According to Lantolf and Thorne (2006), Vygotsky claimed that socioculturally constructed artifacts have the potential to transform elementary functions since these tools allow humans to take control over their biological endowments. At the time Vygotsky conducted his studies, there were no technological advancements like fMRI (functional Magnetic Resonance Imaging) and PET (Positron Emission Tomography), tools that have allowed researchers to actually see what happens in the human brain as a result of interaction with culturally constructed means such as language. Nowadays, however, researchers can access how the insertion of these means may result in changes in the brain, as there is a growing body of studies standing out for showing the way learning to

read changes brain functioning. With this in mind, the next section is aimed at reviewing some of the studies that evidence such a movement.

2 Learning to read and the human brain

By considering that the human brain is the source of human's biologically endowed functions, the understanding that socioculturally constructed artifacts transform them may lead us to assume that this transformation occurs in the brain itself. In this vein, research conducted in the past years in the area of neuroscience has helped researchers better understand this change, a few studies standing out for demonstrating that learning to read alters brain functions. The following paragraphs of this section aim at summarizing some of these studies.

Turkeltaub *et al*.'s (2003) study aimed to investigate the changes in the neural systems responsible for reading throughout its acquisition. In this sense, forty-one healthy participants were included in the final analysis, 22 female and 19 male, aged between 6 and 22 years old. All of them took a test which isolated reading-related brain activity and reduced confounding performance effects. Thus, an implicit word-processing task had participants read tall letters (a visual feature) within both words and matched false font strings. Although participants were not required to read the words, this happened without conscious effort, thus helping minimize performance differences between novice and more experienced readers. Moreover, words were contrasted with visually matched non-lexical stimuli, allowing for the isolation of neurodevelopmental changes related to lexical processing from those related to general brain development. One of the study's main findings was that learning to read led to disengagement of right extrastriate cortex (occipital lobe), indicating a decrease of children's reliance on non-lexical form recognition systems for word identification, which, according to the authors, constitutes the development of a neural basis of reading (along with engagement of left frontal and temporal semantic and phonological processing units).

Dehaene *et al*. (2010) investigated the effects of learning to read on brain functioning. A total of 63 adults of varied literacy backgrounds (10 illiterate, 22 that became

literates as adults, and 31 that were literate in childhood) were investigated. The participants took behavioral tasks constituted of letter identification, word and pseudo-word reading, and sentence reading. The authors concluded that learning to read fosters brain responses in, at least, three ways: (i) by boosting the organization of visual cortices (this being observed through increased strength and specificity of cortical responses to a learned script at the VWFA in left occipito-temporal cortex, as well as increase of early visual responses in occipital cortex); (ii) by leading to activation of great part of left-hemisphere spoken language network (this happening in left posterior, middle, and anterior superior temporal sulcus; left temporal pole; left and right premotor cortex; left inferior frontal gyrus; and left supplementary motor area): and (iii) by refining spoken language processing (this taking place through enhancement of the planum temporale and availability, in a top-down way, of an orthographic code). It is interesting to point out that the results do not circumscribe to reading acquisition only in childhood, but also through adulthood, the neural changes during this latter period of life (*i.e.* increased VWFA response to letter strings; activation of spoken language network through reading; general visual increase in right occipital cortex; greater response of the primary visual cortex to horizontal checkerboards and written sentences; and enhanced planum temporale and top-down activation to both spoken and pseudowords at the VWFA) being considerable ones.

Skeide *et al*. (2017) looked for intrinsic functional reorganization of neural circuits as a result of reading acquisition. The final neural and behavioral analyses counted on 30 illiterate right-handed participants (mean age – 31.63 years old), two of them being males. They were tested as regards their actual letter knowledge and word-reading skills both before and after receiving reading instruction for six months. According to the authors, literacy-induced neuroplasticity increases the connections between the occipital lobe and sub-cortical areas in the midbrain and the thalamus. They concluded that only 6 months of learning to read resulted in great functional reorganization processes in the mature human brain, reshaping the earliest visual computation centers. This was seen as becoming literate in adulthood fostered responses of mesencephalic and diencephalic nuclei, at the same time that activity of the occipital cortex was also enhanced.

Based on previous findings on the role of the visual word-form system (VWFS) in print processing, Brem *et al.* (2010) carried out a study whose main objective was to figure out the point at which sensitivity to print emerges during reading acquisition. The participants were 32 young, healthy, non-reading, and right-handed children in kindergarten. The children performed a modality judgment task that consisted of the following two parts: (i) one in which visual, auditory, audiovisually congruent, and audiovisually incongruent word processing was assessed; and (ii) another in which responses to false fonts and non-intelligible speech were examined. The authors found out that it is during the acquisition of grapheme-phoneme correspondences in young children that print sensitivity in the VFWS rapidly emerges, this movement taking place before full-word reading. Briefly speaking, by comparing the process of learning letter-speech sound correspondences in those children, an initial sensitization to print in specific areas of the occipito-temporal cortex was found – in a bilateral and predominantly ventral posterior occipito-temporal network and in the posterior VWFS. Therefore, it was concluded that occipito-temporal sensitivity is established during the early stages of learning how to read in childhood.

Pegado *et al*. (2014) aimed at assessing the impacts of learning to read on different stages of visual processing (early *vs*. late), as well as evaluating the extent to which early visual processing is already affected. A total of 49 healthy adult subjects (20 males) were included in the final analysis, ages ranging from 32 to 68 years old, all of them having either normal or corrected to normal vision. Besides that, the participants had different levels of literacy, including illiterates, early-schooled literates, and ex-illiterates (those who became literate during adulthood). They all took a test in which they were exposed to six different categories of images, including letter strings forming pseudowords, faces, houses, tools, checkerboards, and false fonts. Then, participants had to look at the stimulus and press a button whenever they saw a black star (an odd target picture). The authors found out that learning to read affects different stages of visual processing, enhancing electrophysiological responses at the post-P1 stage of processing, inducing left-hemispheric lateralization of the N1, enhancing late stage visual processing, improving exemplar discrimination over the left occipito-temporal region, and affecting mirror invariance in the left occipito-temporal region. These results were found in the case

of letter strings and false fonts, but also reverberated on the other aforementioned visual categories. As the authors state, "[…] learning to read impacts the magnitude, precision, and invariance of early visual processing." (PEGADO *et al*., 2014, p. 233).

Schotten *et al*. (2012) carried out a research study whose objective was to explore if learning to read resulted in anatomical changes within the left intrahemispheric white matter pathways that interconnect the cortical regions in the brain that respond to the acquisition of reading. Participants were 31 Brazilian adults that presented similar social origins, but whose level of schooling and literacy varied: there were ten illiterates, ten ex-illiterates who learned to read during adulthood, and 11 literates who learned to read during childhood. They were all presented to words and pseudowords (both through spoken and written language runs). In order to assess the participants' reading performance, the researchers focused on the number of words and pseudowords that could be read by minute. The study was the first one to find evidence of change in the microstructure of the temporo-parietal portion of the left arcuate fasciculus in literates (there was increase in fractional anisotropy and a decrease in perpendicular diffusivity in the temporo-parietal portion of the left arcuate fasciculus)[2] when compared to illiterates. The authors concluded that learning to read leads to parallel changes both in the functional responses in the VWFS and the planum temporale, as well as in the pathway that connects these two regions.

Petersson *et al.* (2007) investigated the role of learning to read in the functional lateralization in the inferior parietal cortex in both literate and illiterate subjects. The study counted on 28 fully functional female participants (14 illiterate) divided into two different groups: (i) there were 12 women — six literate (mean age 63+- 6 years old, 4 years of schooling) and six illiterate (mean age 65 +- 5 years old); and (ii) there were 16 women — eight literate (mean age 58 +- 6,4 years old, 4 years of schooling) and eight illiterate (mean age 63 +- 5years old). For group 1, the participants were presented at a sound level to a list of high-frequency words and a list of pseudowords (that did not vary in length), being instructed to repeat either words or pseudowords during PET scanning. For group 2, lists of word-pairs were auditorily presented, half of them being semantically related and the other half phonologically related. Then, participants were asked to silently listen to those word-pairs and memorize them while they were scanned with their eyes

closed. The results indicate that literate subjects are relatively left-lateralized in comparison to illiterate subjects, signaling that learning to read impacts the functional balance between the left and right inferior parietal region.

In short, the studies reviewed in this section add to the body of research in the area of neuroscience that illustrates how learning to read — a cultural experience — impacts the ways the human brain works and how it restructures and adapts to accommodate the new culturally gained functions. After having presented these studies, the discussion that follows attempts to show how they may align with a sociocultural view on human cognition.

3 Human cognition and reading as a culturally constructed means: building bridges between a sociocultural view and neuroscience studies

As mentioned in the introductory section of this paper, a sociocultural view on human cognition understands that it is the very culturally constructed means around us that foster human cognitive development, being responsible for altering the ways our biologically endowed functions (*i.e.* elementary ones) work. In this context, language (both oral and written) stands out as the most important of these means, its acquisition being paramount for human cognitive development (VYGOTSKY, 1987).

When explaining human cognition, one can say that the movement Vygotsky (1987) advocates for is the one from the external plane to the internal one, the origins of human cognition being external to the individual and constituted of culturally constructed means which are passed down along generations. An intriguing aspect of this movement is that it can be captured (as it has been) in neuroscience studies that focus on the impacts of learning to read on the human brain. As Dehaene *et al*. (2015) claim, when it comes to studies on the relationship between this process and the human brain, there is enough evidence that illustrates how "[…] the brain reorganizes to accommodate a novel cultural skill" (DEHAENE *et al.*, 2015, p. 1), the studies reviewed in the previous section corroborating such a statement.

When considering the human brain the source of our elementary functions, since these are biologically endowed ones, the connection between a sociocultural view on human cognition and the aforementioned studies becomes even clearer, since all those

studies provide evidence of change in brain functions as a result of learning to read. Nowadays, there is consensus that the acquisition of reading is capable of changing both brain anatomy and activation, significantly reshaping cortical organization (DEHAENE *et al.,* 2010).

Moreover, it is important to bring into the discussion one of the main findings of Dehaene *et al*.'s (2010) study. As mentioned before, the authors found out that learning to read activates a great part of the left-hemispheric spoken language network. This finding signals a connection between spoken and written language, as well as shows the way reading — a socioculturally constructed activity — "[…] approaches the efficiency of the human species' most evolved communication channel, namely speech" (DEHAENE *et al*., p. 1364). In this vein, it is widely known that Vygotsky's studies focused primarily on the relationship between oral speech and human cognition. However, the findings here reported somehow relate oral and written language, pointing to an intrinsic connection between these two facets of human communication, as well as how they converse within the human brain. This adds evidence to the sociocultural stance that culturally constructed artifacts (more specifically, language itself) mediate human cognition in ways that propel its development (WERTSCH, 1985).

Last but not least, it becomes essential to point out an important aspect related to brain development itself, which may further help connect a primarily biological and a primarily social approach to the understanding of human cognition. The cerebral cortex develops at a slow pace and its specific parts mature at different points in time in an individual's line of development, possibly being more prone to influences from the environment and from social interaction than other parts of the brain such as the brain stem, which controls more instinctive functions in the body like breathing, digestion, and posture, for example (MARGETTS; WOOLFOLK, 2019). Indeed, Vygotsky's higher mental functions like conceptual thinking, logical reasoning, and decision making are connected to the frontal lobe (part of the cerebral cortex), which is only fully developed around early to mid-twenties. Needless to observe, this further fosters the present discussion by signaling that the relations people establish with the world around them do have the potential to propel the development of such mental functions.

In short, the discussion points to an integrative relation between a primarily biological and a primarily social approach to the understanding of human cognition. The results presented throughout this paper illustrate the effects of learning to read — a culturally constructed activity — on reorganizing brain activity, which highlights the development of human cognition "[...] in terms of the relationship between natural and cultural forces." (WERTSCH, 1985, p. 48). Needless to observe, the present discussion concurs with Vygotsky's view of development as the reviewed studies show how learning to read — an activity that initially takes place on the external plane — results in changes in our internal mental plane. With this in mind, it seems reasonable to acknowledge both nature and culture's role when discussing human cognition, thus adopting a complementary view of human mental development.

Final remarks

The present paper's objective was threefold: first, it was aimed at presenting a sociocultural view on human cognition; second, it intended to review studies on the impacts of learning to read on brain activity; and third, it attempted to draw a parallel between Vygotsky's view on human cognition and neuroscientific evidence about the changes that take place in human brain activity as we learn to read. Seven articles in the area of neuroscience were reviewed in order to foment the present discussion with evidence that illustrates the ways learning to read affect brain activity. It could be seen that learning to read impacts the brain in different ways, leading to the development of a neural basis for reading (TURKELTAUB *et al*., 2003), fostering different forms of brain responses (DEHAENE *et al*., 2010), reorganizing processes in the mature human brain (SKEIDE *et al*., 2017), enhancing the emergence of sensitivity to print in the VWFS (BREM *et al*., 2010), affecting different stages of visual processing (PEGADO *et al*., 2014), changing the microstructure of specific brain regions (SCHOTTEN *et al.*, 2012), and impacting functional balance between the left and right inferior parietal region (PETERSSON *et al.*,2007).

It is argued, in this paper, that these results illustrate the ways a neuroscientific approach to reading acquisition may align with a sociocultural view on human cognition, showing how learning to read results in changes in brain activity and how the brain reorganizes itself in order to accommodate new functions gained through cultural interaction. With this in mind, it would be interesting to see whether such changes have the potential to lead to development in the philogenetic domain. Briefly presenting, Vygotsky came up with different domains in his approach so as to account for human mental development: phylogenesis, which has to do with organic evolution of the species; sociocultural history, which encompasses social human life; ontogenesis, which accounts for an individual's sociobiological formation (phylogenesis plus sociocultural history); and microgenesis, which involves the development of specific cognitive processes during one's history (WERTSCH, 1985)[3]. A widely criticized claim Vygotsky held was that "[...] organic evolution [...] proceeds up to a point where culture can emerge and then this evolution ceases." (WERTSCH, 1985, p. 29). According to Wertsch (1985), the genesis of culture can be seen to a time that precedes the end point of organic evolution, thus the "[...] biological substrate of mental processes may have emerged partially in response to cultural pressures." (p. 30). This does not, by any means, weakens Vygotsky's proposal, since his main focus was on the ways social interaction fosters cognitive development. As previously mentioned, one should keep in mind that there were very few technological advancements when he conducted his studies. That being showed, looking for organic changes in the human brain which result from the processes of learning how to read is a tentative long-term research proposal from a sociocultural approach, since its emphasis lies on social interaction.

In conclusion, when drawing this parallel, it is essential to keep in mind the relationship between the external world around the individual and their internal world advocated by Vygotsky (1987), which means that transformation of biologically endowed functions (*i.e.* elementary ones) — those that originate in the human brain — result from people's contact to sociocultural tools (in the present case, reading). The present paper can be taken as a claim for a complementary view of human cognition, one that takes into account both people's internal and external worlds when looking into what is involved in the development of higher forms of human mental functioning.

Notes

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[1] The terms “means”, “artifacts”, and “tools” are used interchangeably in this piece of work as it is traditionally done in Vygotskian-based studies.

[2] “Anisotropy” is understood as “the directional dependence of diffusion [of protons] seen in biological systems” (Winston, 2012, p.254). “Fractional anisotropy” and “perpendicular diffusivity” are paremeters used in diffusion magnetic resonance to “[...] provide sensitive, but non-specific, measures of altered tissue structure” (WINSTON, 2012, p. 254). For more information on those measures, see Winston (2012).

[3] For more information on Vygotsky’s genetic domains, see Wertsch (1985).

References

BREM, Silvia *et al*. Brain sensitivity to print emerges when children learn letter-speech sound correspondences. **Proceedings of the National Academy of Sciences of the United Stated of America***,* Washington DC, v.107, n.17, p. 7939-7944, April. 2010. DOI: https://doi.org/10.1073/pnas.0904402107

DEHAENE, Stanislas *et al.* How Learning to Read Changes the Cortical Networks for Vision and Language. **Science Magazine**, Washington DC, v.330, n.6009, p. 1359-1364, December. 2010. DOI: https://doi.org/10.1126/science.1194140

DEHAENE, Stanislas *et al.* Illiterate to literate: behavioural and cerebral changes induced by reading acquisition. **Nature Reviews Neuroscience**, New York, v.16, n.4, p. 234-244, March. 2015. DOI: https://doi.org/10.1038/nrn3924

FERNYHOUGH, Charles. The dialogic mind: A dialogic approach to the higher mental functions. **New Ideas in Psychology***,* Amsterdam, v.14, n.1, p. 47–62, March. 1996. DOI: https://doi.org/10.1016/0732-118X(95)00024-B

LANTOLF, James P; THORNE, Steve L. **Sociocultural Theory and the Genesis of Second Language Development***.* 1st Ed. Oxford: Oxford University Press, 2006, 416p.
MARGETTS, KAY; WOOLFOLK, ANITA HOY. **Educational Psychology**. 5th Ed. Melbourne: Pearson Australia, 2019, 625p.

OLIVEIRA, MARTA KOHL. **Vygotsky**: Aprendizado e desenvolvimento, um processo sócio-histórico*.* 4th Ed. São Paulo: Scipione, 2001, 111p.

PEGADO, FELIPE *et al*. Timing the impact of literacy on visual processing. **Proceedings of the National Academy of Sciences of the United States of America***,* Washington DC, v.111, n.49, p. 233-242, December. 2014. DOI: https://doi.org/10.1073/pnas.1417347111

PETERSSON, KARL MAGNUS *et al*. Literacy: a cultural influence on functional left–right differences in the inferior parietal cortex. **European Journal of Neuroscience**, London, v.26, n.3, p. 791-799, August. 2007. DOI: https://doi.org/10.1111/j.1460-9568.2007.05701.x

SCHOTTEN, MICHEL THIEBAUT DE *et al.* Learning to Read Improves the Structure of the Arcuate Fasciculus. **Cerebal Cortex***,* New Haven, v.24, n.4, p. 989-995, April. 2012. DOI: https://doi.org/10.1093/cercor/bhs383

SKEIDE, MICHAEL *et al*. Learning to read alters cortico-subcortical cross-talk in the visual system of illiterates. **Science Advances***,* Washington DC, v.3, n.5, p. 1-7, May. 2017. DOI: https://doi.org/10.1126/sciadv.1602612

TURKELTAUB, PETER E. *et al*. Development of neural mechanisms for reading. **Nature Neuroscience***,* New York, v.6, n.6, p. 767-773, July .2003. DOI: https://doi.org/10.1038/nn1065

VYGOTSKY, LEV SEMYONOVICH. **Mind in society**: the development of higher psychological processes. 1st Ed. Cambridge: Harvard University Press, 1978, 159p.

VYGOTSKY, LEV SEMYONOVICH. **The collected works of LS Vygotsky**: Problems of General Psychology. Including the Volume Thinking and Speech. R. W. Rieber; A. S. Carton (Eds.). 1st Ed. New York: Plenum Press, 1987, 396p.

WERTSCH, JAMES V. **Vygotsky and the Social Formation of Mind**. 1st Ed. Cambridge: Harvard University press, 1985, 262p.

WINSTON, GAVIN P. The physical and biological basis of quantitative parameters derived from diffusion fMRI. **Quant Imaging Med Surg**, Rockville, v.2, n.4, p. 254-265, December. 2012. DOI: https://doi.gov/10.3978/j.issn.2223-4292.2012.12.05

WOOLFOLK, ANITA HOY. **Educational Psychology**. 13th Ed. Boston: Pearson Education Limited, 2016, 623p.

Recebido em: agosto/2020
Aprovado em: junho/2021