

Review



# A brain-based model of language instruction: from theory to practice

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## Abstract

**Background:** A recent trend in second language acquisition and learning has been oriented towards brain-based studies and its association with brain development and plasticity. There are currently unprecedented opportunities for contemporary understanding of the neurological basis of second language (L2) learning owing to recent advances in cognitive neuroscience. Brain functional and structural investigations have contributed remarkably to biological explanations of language acquisition in addition to behavioral explorations.

**Methods:** This study used a meta-analysis of previous findings of functional neuroimaging studies to elucidate the neuroanatomy of language learning from a functional perspective. By synthesizing existing literature, brain activation areas associated with different language learning skills and their convergence and overlap with other areas of activation for other cognitive and motor skills are extracted to reveal consistent functional areas of the brain. The current study attempts to link psycholinguistic research and cognitive neuroscience in the mediation of L2 learning and teaching. This review paper begins with a theoretical view of brain structure and function and concludes with a practical model of brain-based language instruction, resulting in a deeper understanding of the field.

**Results:** Organized, conjoining cognitive neuroscience findings and L2 acquisition and learning approaches provide an opportunity for collaboration in cross-disciplinary studies. They provide new insights into how our brain represents languages. This article reviews recent advancements in our understanding of the brain; structural and functional organization of the brain; the role the brain plays in emotion, cognition, and development; and its consequent implication in language instruction. In effect, taking neurocognitive findings into account may have potential in developing brain-based tasks for the benefit of second language instruction in educational settings. Based on the revealed structural and functional areas of the brain and their networks of connection and interaction, manipulating areas of demanded activity may be as efficient as doing physical exercise to strengthen muscles.

**Conclusion:** Developing a systematic model of second language instruction compatible with brain functions and patterns can benefit the rate and proficiency of language learners, thus improving language teaching and learning outcomes. This paper will aid the quest for utilizing general information of brain functions and related methods in developing practical, efficient language instruction as well as enhancing interdisciplinary research studies in both language and cognitive neuroscience.

## Introduction

Neuro-imaging studies and methodologies have provided the means for cognitive researchers to track changes in the brain in response to language and other experiences. Owing to advancements in medical technology, a growing number of neuroimaging and functional neuroimaging studies have been conducted that illuminate the complex organization, processing, and procedures of language acquisition and learning in the brain. L2 learning research has also kept pace with such developments. In the last two decades, new perspectives have emerged in language

research; as affirmed by Abutalebi,<sup>1</sup> we have a better understanding of the brain-language relationships to the extent that even neural networks underlying different domains of language processing can be identified with considerable precision. Cognitive neuroscience provides the benefits of several methods, including functional magnetic resonance imaging (fMRI),<sup>2</sup> Diffusion Tensor Imaging (DTI),<sup>3</sup> electroencephalography, and event-related potentials (for a recent review, see Beres<sup>4</sup>), Functional Near-Infrared Spectroscopy<sup>5</sup> (for a general review, see Pinti et al<sup>6</sup>), and magnetoencephalography<sup>7</sup>

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has enabled scientists to examine the impact of second language use. The main advantage of these methods is that they help in tracking brain functions while the brain is processing language. Examining brain structure regarding language learning has so far been made possible using MRI and DTI methods concerning changes in the volume of grey and white matter.

One recent approach for optimizing L2 learning and informed L2 teaching is brain-based learning. This trend has brought together the sciences of neurology, psychology, and education and is largely supported by advanced brain scanning, as brain activities and their structural changes are able to be observed either during language processing or as consequences of second language acquisition. Caine and Caine,<sup>8</sup> pioneers in brain-based science, proposed 12 principles that underlie the brain-based learning approach and educational brain-based research. These principles are as follows: 1- Brain processes in parallel, 2- Learning engages the entire physiology, 3- The brain's search for meaning is instinctive, 4- The search for meaning is based on patterns, 5- Sentiments are significant to making patterns, 6- Perceiving and creating parts and wholes occur simultaneously, 7- Two types of attention, focused and peripheral, are involved in learning, 8- Learning process can be both conscious and unconscious, 9- Memory system entails spatial memory and rote learning, 10- Learning occurs as a result of the integration of skills and facts in long-term memory, 11- Challenge enhances and threat inhibits learning, and 12- Every brain is the only one of its kind.

Immordino-Yang et al<sup>9</sup> associated brain development with three integrated requirements for learning and adaptability to the environment: cognitive opportunities, emotional experiences, and social relationships. Accordingly, educational policymakers and practitioners have turned to such brain-based evidence to draw basic principles for optimal learning and language learning in particular. The human brain consists of several, different, and interacting networks, and their relevant studies have featured a systematic framework for apprehending the underpinning aspects of the human brain organization regarding its structures and functions.<sup>10</sup> The identification and characterization of these networks have greatly elucidated our pathway towards understanding the brain's mechanism and its function in identifying biological and cognitive events that guide responsive behavior.<sup>11,12</sup> The networks of the brain and their connectivity have dominated the landscape of cognitive neuroscience.<sup>13</sup> The traditional view of brain modularity and the pertinence of discrete regions to distinct functions has ushered in models emphasizing large-scale brain networks and their dynamics and connectivity underlying cognition.<sup>10,14</sup> Biswal and colleagues, who initially utilized the method of resting state fMRI, successfully studied connectivity of functions in the region of the brain's motor system under the condition of not performing any tasks,<sup>15</sup> and provided

a powerful tool for discovering the natural architecture and network configuration of the human brain.

For this review paper, we begin with a brief overview of the language-related structural and functional brain regions and a review of three large-scale networks allied with their structures and functions. In order to achieve an operationally systematic model for L2 instruction based on brain functions, this study takes as its basis the recent view of the brain as the connectome, or brain network connectivity. The term "connectome" was introduced in 2005 by Hagmann and describes the set of all neural connections. According to Sporns et al,<sup>16</sup> the human connectome refers to a neural map that presents connections and linkages among neural, structural, and functional organizations of the brain, associated with a connection matrix or network. Taking into consideration the fact that cognitive functions emerge from the dynamics of extended cortical and subcortical networks, connectome theory, with the application of graph theory, has recently begun to shed light on the way human cognitive functions integrate with neural network structures.<sup>17</sup> Graph theory is a constructive theory that has emerged in this domain; it is a mathematical representation of the architecture of the brain which comprises a set of nodes and links. According to graph theory, nodes are related to brain regions, and links stand for anatomical, functional, and effective connections.<sup>18,19</sup> Neuroimaging studies and more recently functional imaging investigations have offered evidence to support the connectivity hypothesis of brain regions both structurally and functionally at the level of micro-scale (neurons and their synaptic connections) and macro-scale networks. As proposed by Immordino-Yang et al,<sup>9</sup> the default mode network (DMN) is in charge of making meaning, reflection, and memory, the Salience Network (SN) deals with emotional relevance, and the central executive network (CEN) manages flexible attention and task productivity. This study, in line with other neuroimaging research, supports the idea that a considerable part of mental capacity, contributing to social, emotional, and cognitive functioning such as facilitating attention, reflecting thought, and subjective evaluation, requires coordination and co-regulation of these three large-scale networks. They highlight both the interconnectivity of brain functions, and the fact that social relationships, emotional experience, and cognitive resources are essentially required for brain development to take advantage of learning opportunities. The triple network model as presented in [Figure 1](#), consisting of the DMN, SN, and the CEN was used for the current study based on their functional connectivity in human learning tasks.

Applied linguists, working in tandem with cognitive neuroscientists in the field of second language acquisition and learning, have been pursuing collaborative efforts in bringing applied linguistic studies into cognitive neuroscience research. Accordingly, the current study

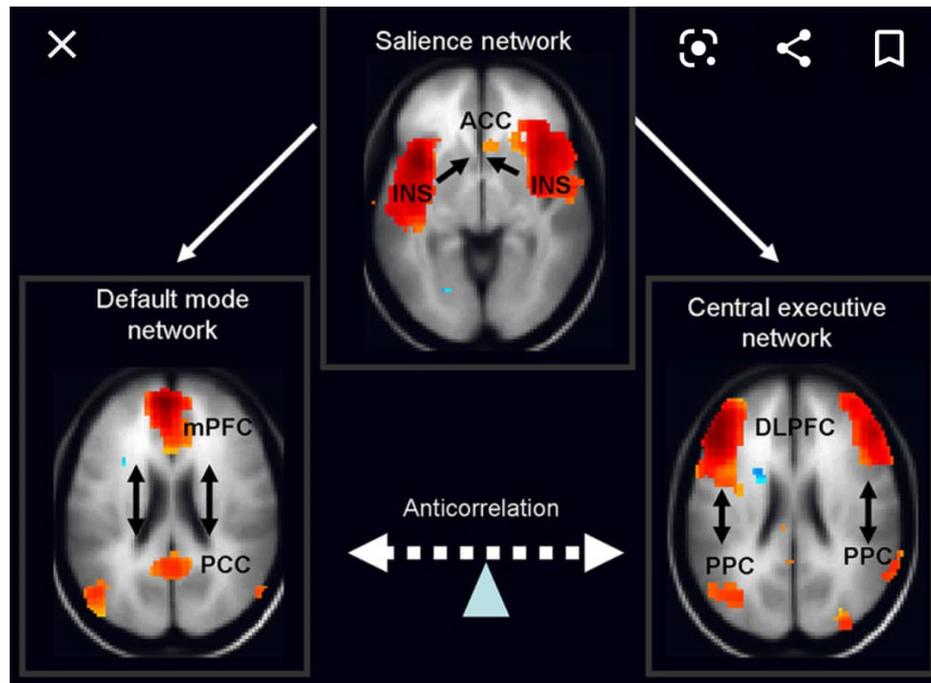


Figure 1. which includes the reference and copyright permission.

aims to establish a link between research methodologies in cognitive neuroscience and pedagogical language studies to bridge the gap between academic and applied knowledge.

### ***Salience network***

SN is a large-scale brain network located in the dorsal anterior cingulate cortex and the anterior insula. It has three main structures in the subcortical regions: the ventral striatum, the amygdala, and the substantia nigra/ventral tegmental area. The network perspective of the brain has led to several brain imaging studies featuring these regions in numerous affective and cognitive processing. The SN, parallel to other networks of the brain, supports a wide range of brain functions comprising social manners, communication, and self-awareness in combination with cognitive, emotional, and physical information.<sup>11,21,22</sup> It has also been implicated in weighing appropriate and significant emotions and perceived information to intervene in switching between the DMN (internally directed signals) and the CEN (externally directed signals).<sup>23,24</sup> The insula is thought to have a key role in detecting new significant stimuli through several modalities. The studies also describe the insular cortex effect in various cognitive functions associated with insight, emotion, and interactive experiences.<sup>24</sup> Various psychiatric disorders, such as post-traumatic stress and anxiety disorders, dementia, and diseases related to schizophrenia and Alzheimer's, have been attributed to SN dysfunction in the reviewed studies.<sup>25</sup> Lesion studies of the brain in both humans and monkeys illustrated the essential involvement of the anterior cingulate cortex in particular to social behavior and emotion.<sup>26,27</sup> Studies have

also shown that SN is activated in situations in which it may be important to change behavior.<sup>28</sup> For instance, errors are associated with SN activation<sup>29</sup> and signal behavioral adaptation.<sup>30</sup>

### ***Default mode network***

DMN is another large-scale network of increasing interest to researchers. This anatomically defined and interconnected set of brain regions constitutes the prefrontal cortex in the medial area, the medial temporal lobe, the cingulate cortex in the posterior area, the ventral precuneus, the angular gyrus, and parts of the parietal cortex. It is heavily involved with the act of daydreaming.<sup>31,32</sup> This network is most active when we are not particularly focused on anything and is involved in the so-called "theory of mind" that is processing the psychological self, building coherent narratives, thinking about beliefs and self-values, and calling up personal memories.<sup>33,34</sup> It is deactivated during cognitive task performance.<sup>35,36</sup> When there are no external task demands, this network activates.<sup>37,38</sup> Processing cognitive functions such as thinking for the future and daydreaming that necessitate internal and self-generated thoughts,<sup>39-43</sup> as well as creativity,<sup>44</sup> are associated with this network. Creative thinking tasks such as divergent thinking also revealed activation of DMN in both structural<sup>45,46</sup> and functional imaging studies of differing thoughts.<sup>47-49</sup>

### ***Central executive network***

The CEN the third large-scale network considered in this study and is primarily composed of the anterior cingulate cortex, the dorsolateral prefrontal cortex, and the posterior parietal cortex around the interparietal

sulcus, the dorsomedial thalamus, and the head of the caudate nucleus.<sup>12,25,50</sup> This network is thought to maintain information and manipulate data in working memory and its role in making decisions and solving problems in the quest for goal-directed tasks.<sup>20</sup> Other functions specified to be related to this network include attention, concentration, holding information in mind, working memory,<sup>51</sup> and planning and carrying out goal-directed tasks<sup>52,53</sup> as well as emotional processing tasks. It is thought that processing new information, regulating emotion, and detecting distractions and unessential information in the environment can also be attributed to this network.<sup>54</sup> CEN shows prominent activation during cognitive and emotionally thought-provoking activities. To sustain attention, the lateral posterior parietal cortex, as one of the major nodes, manages sensory information and distractions. In addition to its role in making practical decisions, CEN is also associated with processing task-oriented (e.g., top-down) functions necessary for the active regulation of emotions.<sup>55</sup> Depression and numerous cognitive malfunctions have also been attributed to hypoactivity of CEN.<sup>20</sup>

### Materials and Methods

With the advent of functional neuroimaging and neurophysiological studies, a new wave of research has moved toward the neural organization of learning, behavior, and language. We can see cumulative attention to the idea that functions that the cortical regions are responsible for have overtaken the old assumption of left perisylvian areas in language learning.<sup>56</sup> The issues of brain modularity and localization have been scrutinized, since brain imaging offers accessibility to brain pattern activities. The approach taken in this review study to explain the cognitive functions of language learning from a neuroanatomy perspective is a meta-analysis of previous functional neuroimaging studies by Tagarelli et al.<sup>57</sup> Through synthesizing the existing literature, the areas of brain activation associated with different language learning skills and their convergence and overlap with other areas of activation for other cognitive and motor skills have been extracted to reveal consistent functional areas of the brain. The current research is a review study aiming at linking cognitive neuroscience studies and psycholinguistic research in L2 acquisition and learning. This review paper conforms to standard methodological guidelines of systematic reviews. First, a literature search was performed to identify brain-based studies, including education and language instruction. Following the initial search, the titles and abstracts of the articles were extracted. The full texts of the articles were then retrieved. As is common with review papers, areas of consensus and similarities in several neuroimaging and brain mapping studies were extracted to lay the foundation of the study. Taking into account the structural organization and functional configuration of the above-mentioned

three large-scale networks, the extracted structural and functional regions have been categorized as their subnetworks. We focused on their identification, marking their fundamental nodes and their patterns of connectivity. A model that presents a cycle of enhanced connection is provided, based on the connectome theory. The paper concludes with a practical model of brain-based language instruction to lead to a deeper understanding of this field.

### Results

Based on reviewed literature of several functional neuroimaging and brain-mapping studies conducted in the past decade, evidence has been provided that speech and language functions are processed not only within the Broca-Wernicke areas but also in the right perisylvian cortex in collaboration with other cortical and subcortical networks. Moreover, pathways and tracts for processing language have also been traced to form cortical connections. The dorsal and ventral streams, for instance, have been identified as noticeable pathways in the neurobiology of language. New methods and statistical analysis have helped develop both classic and contemporary models of language connectivity and connectome based on the distributed cortical and subcortical areas and their relevant functions. These models represent theoretical frameworks for language network processing and production.

From a larger perspective, the structural and functional areas of the triple network have also been shown through neuroanatomical analysis. Beyond language functions, other cognitive functions have also been attributed to these networks.<sup>58</sup> Table 1 represents the acquired data of the reviewed literature based on certain brain regions and their pertinent functions.

To convert the acquired data into a more comprehensive template and regarding the triple large-scale networks' properties, the extracted brain regions were categorized as related subnetworks. Table 2 represents the categorized distributed areas as subnetworks of the triple large-scale networks.

The categorized data reinforces the connectome theory and its application in cognitive science and educational and medical methodology. Accordingly, the extracted and consequent categorized data in this review study provide a brain-based model of language instruction.

### *Developing an educational brain-based model*

The acquired knowledge of the brain models is to encourage teachers to reflect on their methodology and lesson plans in ways that are advantageous for students' effective learning. To meet this goal, a model should be constructed in a way that not only explains data and behavior but is useful. A good instructional model will follow recent findings in various fields of research. The following model is proposed, taking into account the twelve brain principles (1- Brain processes in parallel,

**Table 1.** Brain regions and functions

Brain Regions	Functions
Frontal lobe	connecting Broca - Wernicke areas, taking over phonological and verbal repetition processing, syntactic structures complexity, decision making, planning, problem-solving, and creativity
Prefrontal lobe	metacognitive functions, sensory-motor cognition, and integration, emotions, personality, working memory, and attention
Parietal lobe: supramarginal gyrus and region behind, angular gyrus	retrieving words and numbers, reading
Anterior temporal lobe	representations and retrievals of social information through recalling peoples' profiles and forms of social memory such as personal traits and processing social concepts
Left superior temporal gyrus, temporal pole, and angular gyrus and between the right superior temporal and superior parietal lobe connectivity	attention and visuospatial function
Anterior inferior frontal gyrus and posterior superior middle temporal cortices	controlling retrieval of semantic representations or long-term lexical storage
Superior temporal gyrus, inferior parietal and angular gyrus of the parietal lobe (Wernicke's areas)	Speech comprehension
Left superior, middle inferior temporal gyri	processing words, sentences, and paragraphs
Inferior frontal gyrus (Broca's area); pars orbitalis, pars triangularis	involved in speech production; syntactical complexity, semantics, and phonology
Anterior cingulate and anterior medial prefrontal cortex	initiating motor cortex functions such as speech, spontaneity, attention and emotion, inner processing, and using language for thinking while it is not working
Inferior parietal gyrus and its link to the dorsolateral cortex and inferior frontal gyrus	working memory and attention necessary for verbal communication, recognizing emotions and emotional effect in others
The temporo-parietal junction and superior temporal sulcus	distinguishing self from others and playing a role in the affective TOM or the skill of realizing the emotional temperament of another
Posterior cingulum / precuneus and dorsomedial prefrontal cortex cluster	TOM, reference to the self, and biographic knowledge of self
Anterior cingulum, ventral striatum, ventromedial prefrontal cortex and subgenual cingulum	social behavior, motivation, reward, and affective self-management
Right inferior frontal gyrus	initially engaged during foreign language acquisition, but disengaged in retention of long-term language skills
Inferior medial frontal lobe, temporo-parietal junction, and medial temporal lobe	empathy
Left inferior frontal gyrus, middle temporal gyrus, and parahippocampal gyrus	supporting word learning
Amygdala	regulating emotions such as fight or fear, defensive reactions, and memory encoding
Hippocampus	interacting with the temporal lobe to help establish episodic memory
Insula is the large fissure that separates the frontal and parietal lobes from the temporal lobe	playing a role in consciousness and varied functions related to emotions such as compassion, empathy, taste perception, motor control, self-awareness, social experience, personal emotional experience, and basic emotions like; disgust, anger, happiness, fear, and sadness
Dorsal stream pathways	organizing sequential elements
Ventral stream pathways	processing meaning (in language production; semantic to lexical mapping and in language perception; lexical to semantic mapping)

2- Learning engages the entire physiology, 3- The brain's search for meaning is instinctive, 4- The search for meaning is based on pattern, 5- Sentiments are significant to making patterns, 6- Perceiving and creating parts and wholes occurs simultaneously, 7- Two types of attention focused/peripheral are involved in learning, 8- Learning process could be both conscious and unconscious, 9- Memory system entails spatial memory and rote learning, 10- Learning occurs as a result of the integration of skills and facts in long-term memory, 11- Challenge enhances and threat inhibits learning, and 12- Every

brain is the only one of its kind). Together, constructing the brain-based learning approach and the connectivity of brain networks, collaboration and co-regulation of the three networks help bring about a systematic activation of the networks that can be conducive to efficient learning.

### ***Saliency network***

Active: in situations in which it may be important to change behavior, behavioral adaptation (brain processes in parallel).

Function: communication, social interaction, and

**Table 2.** The triple large-scale networks and related sub-networks

Central executive network	Default mode network	Salience network
Anterior inferior frontal gyrus and posterior superior middle temporal cortices	Superior temporal gyrus, the inferior parietal and angular gyrus of the parietal lobe (Wernicke's areas)	Anterior cingulate and anterior medial prefrontal cortex
Inferior frontal gyrus (Broca's area); pars orbitalis, pars triangularis	Left superior, middle inferior temporal gyri	Insula is the large fissure that splits the frontal and parietal lobes from the temporal lobe
Frontal lobe	Parietal lobe: supramarginal gyrus and region behind, angular gyrus	Amygdala
Prefrontal lobe	Left superior temporal gyrus, temporal pole, and angular gyrus and between the right superior temporal and the superior parietal lobe connectivity	
Anterior cingulum, ventral striatum, ventromedial prefrontal cortex and subgenual cingulum	Inferior parietal gyrus and its link to the dorsolateral cortex and inferior frontal gyrus	
Right inferior frontal gyrus	The temporo-parietal junction and superior temporal sulcus	
	Anterior temporal lobe	
	Posterior cingulum / precuneus and dorsomedial prefrontal cortex cluster	
	The inferior medial frontal lobe, temporo-parietal junction, and medial temporal lobe	
	Left inferior frontal gyrus, the temporal gyrus in the middle, and the Para hippocampal gyrus	
	Hippocampus	

self-awareness (sentiments are significant for making patterns, learning process could be both conscious and unconscious).

### **Default mode network**

Active: when building coherent narratives, thinking about beliefs and self-values, calling up personal memories, and creative thinking tasks (two types of attention focused/peripheral are involved in learning)

Function: cognitive processing of directed or self-generated thoughts (the brain's searching for meaning is instinctive, the search for meaning is based on a pattern)

### **Central executive network**

Active: during emotionally and cognitively challenging tasks (challenge enhances and threat inhibits learning).

Function: decision-making, problem-solving, goal-directed behavior (perceiving and creating parts and wholes occurs simultaneously), attention, concentration, and holding information in mind (learning engages the entire physiology), working memory (memory system entails spatial memory and rote learning, learning occurs as a result of the integration of skills and facts in long-term memory). It is also important for regulating emotions and processing challenging information (every brain is the only one of its kind).

To provide an example, a task related to the systematic activation of the three networks is suggested in this study.

In a classroom discussion, students should:

- Talk about emotionally challenging topics; for example, discussing social phobia (*CEN*)
- Play different roles in discussions: participant,

organizer, prompter, etc. (*SN*)

- Talk about their personal experiences and memories of social phobia (*DMN*)
- Find the origins of their social phobia and propose some solutions (*CEN*)

**Outcome:** They can communicate in L2, goals are self-generated, and they are goal-directed.

### **Discussion**

Regarding the analyzed distributed brain structural and functional areas as sub-networks of the triple large-scale networks, a model has been developed based on the connectome theory. In contrast with the paradigm of brain modularity in which single brain areas operate independently to process and produce cognitive functions, the new trend of brain network connectivity and interaction emphasizes emerging brain functions because of conjoint actions of distributed areas. This process of developing this brain-based model is analogous to reverse engineering.

The structural and functional architecture of the large-scale networks and their subnetworks help us realize how cognitive functions such as different aspects of language learning, emotional arousals, problem-solving, and affective reactions emerge. It also aids neurocognitive scientists to make pathological or psychopathological inferences of local areas of defects through knowing that change in one area can cause changes to other areas.

The potential value in conducting reverse engineering is to develop a subsequent brain-based model represented in [Figure 2](#). By deliberate activation of the areas of desired functions, a pattern can be established to reinforce



Figure 2. developing an educational brain-based model .

connectivity and interaction within and between the triple networks. For instance, some qualities are essential to consider in order to communicate effectively in a first or foreign language. At the level of language components, for example, word learning and processing, syntax and semantics, phonetics, speech comprehension, and production, and their related brain areas of function are delineated. Beyond the level of language components, related cognitive functions such as emotional regulation, social interactions, experience, and memory are quite significant and their related brain areas are also neurologically marked. Hence, performing tasks that activate these areas of configuration in such a way that each quality reinforces the other provides a systematic cycle of an enhanced model of learning which can be further examined to be put into practice.

Thus, if we consider language instruction a cycle, where tasks of interaction reinforce the experience, good experiences induce positive emotions which accordingly reinforce memory, then moving toward an inclination to interact effectively; and so the cycle continues. These activities are projections of the underpinned interdependent brain network functions.

### Conclusion

Studying brain networks, especially concerning their structure and function, opens new insights in the

procedure and processing of language acquisition and improves operational pedagogies for language teaching and learning. The still-growing studies of brain networks and examinations of interactions within and among these networks have helped with psychiatric and neurological disorders and psychopathological investments.<sup>59-63</sup> Additionally, they are significant additions in the educational fields of both L1 and L2. Developing these teaching methods and principles based on the brain connective theory and the dynamics within and between brain networks as they evolve<sup>64,65</sup> provides learners with educational settings that can be remedial for learners suffering from learning disorders at the level of receiving, perceiving, and producing learning materials and upgrading for learners with normal learning abilities. Designing tasks and pedagogical teaching materials based on the brain's structural connectivity and areas of cognitive functions can improve educational outcomes, including learning and creativity, self-investment, and resilience. The process, in addition, could be bottom-up, given that implementing neuroimaging techniques and methods can trace, confirm, and substantiate structural and functional brain connectivity. More specifically, the involvement of brain-based directed social interaction tasks can maximize individual learning potential. Developing brain-based entertainment and recreational activities for aging populations could also prevent, delay, or ameliorate

dementia, which is growing among the elderly. Brain-based studies can combine medical developments with language instructional tasks.

It is worth considering that the cognitive neuroscience methods reviewed here are tools that can be effectively applied in combination with meaningful content knowledge. Integration of language instruction and brain networking has theoretical and practical implications to elevate our knowledge of the brain's operational system and the neural mechanism responsible for language learning. Indeed, the potential ability of humans to learn and the effect of the environment on human development has provided novel chances for researchers in different disciplines. Neuroimaging techniques have aided researchers in tracking changes in the brain, which expands our understanding of the brain structure. The current paper is a starting point for researchers who are interested in neuroimaging investigations and medical education. Medicine and educational collaboration develops both fields and provides a better understanding of language use concerning brain structure and function.

#### Ethical approval

All the technical terms and concepts as well as quotes are referenced. The image used in the study is subject to copyright; however, the source is fully cited.

#### Competing interests

No competing interest exists among all the authors. No financial support or fund is received for conducting this research.

#### Authors' contributions

Active collaboration and cooperation of all the authors have been applied to all parts of the study. FI conceived the idea and prepared the manuscript, MHN offered subject-specific insights and MG contributed to content organization. All authors reviewed the final manuscript.

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