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The Effect of Co-speech Gestures on Learning a Foreign Language: A Systematic Review

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Abstract

This study is, largely, a systematic review that identifies and synthesizes research data from different resources with the aim of drawing conclusions about the effect of co-speech gestures on learning a foreign language (FL). We used PubMed and PubMed Central as the databases for our search; we narrowed the search mainly to experimental psychology and neuroscience studies that focus on the effect of gesturing on learning/learning a foreign language. Analysis of our synthesis of research in cognitive psychology and neuroscience suggests that gesturing positively affects learning in general. Interest in investigating the effect of gesturing on learning a foreign language appeared recently, and most studies in this area focus on teaching and learning foreign language vocabulary; however, research in this area is still limited in comparison to research on gesturing and cognition in general. The reviewed cognitive psychology studies suggest that gesturing enhances FL learning efficiency and memory retrieval. Research in modern neuroscience agrees that gesturing strengthens the neural interconnectedness of the cognitive process involved in learning a foreign language; this especially concerns supporting the networks of sensory and sensorimotor representations of words in the brain. Research in cognitive psychology and neuroscience provides strong evidence that gestures enhance and aid foreign language learning.

Keywords: co-speech gestures, gestures and learning, gestures and learning a foreign language.

INTRODUCTION

Gestures can be described as non-verbal behavior that communicates a message. Hand and arm gestures that accompany utterances can visually resemble and embody information about shape, distance, size, and motion rather than just convey such information as words usually do (Mathias et al., 2021a; Wagner, 2014; Kang & Tversky, 2016). The word 'sliding', for instance, represents the action of sliding while the sliding motion of the hand both represents and resembles the action of sliding. In most situations, humans use gestures spontaneously and involuntarily when explaining to others (Alibali et al., 2017; Bach et al., 2010; Cole, et al., 2002). Humans gesture even when the addressee cannot see these gestures, as when blind speakers use gestures while talking to blind listeners (Iverson & Goldin-Meadow, 1998), people also gesture while talking on the phone (Bavelas et al., 2008). These findings lead us to think that the purpose of gestures is not merely to communicate messages but that gestures also have a possible inherent role in thinking, speech production, and learning (Mathias et al., 2021a; Choi et al., 2021; Sweller et al., 2020).

A good number of studies in cognitive psychology, neuroscience, and psycholinguistics have focused on the multifunctional role of co-speech gestures and

their effect on the interactants' cognitive status. This study aims to investigate research focusing on enhancements that co-speech gestures can bring to learning a FL.

In order to investigate recent findings concerning the effect of co-speech gestures on learning a foreign a language, the study aims to find answers to the following questions:

1. Does research in cognitive psychology provide evidence concerning the effect of using co-speech gestures on the learning of a foreign language?

2. What are the findings in neuroscience concerning the effect of gestures on learning a foreign language, and do these agree with the findings in cognitive psychology?

This study progresses as follows: we provide, first, a background about the description of gestures in the literature, then we investigate the integration of gesture and speech; after that we investigate how gesturing facilitates language production, comprehension, and memory retrieval; next, we study how gestures benefit learning in general, this is followed by investigating how gestures benefit learning a FL. The conclusion summarizes findings and gives suggestions for further research.

Background and Literature Review

McNeill (1992) classifies gestures into iconic (also 'representational') gestures, deictic gestures, emblems, and beats (see also Biau et al., (2016) and Vainger et al., (2014)). Iconic gestures depict shapes, actions, or events, and the connection between form and meaning is usually not conventionalized and non-arbitrary since many iconic gestures visually represent the entities to which they refer (McNeill 1992). Iconic gestures can be taken as an embodiment of meaning in a physical representation (Kelly, et al., 2009, p. 314). These gestures, in particular, do not only convey meaning, but, perhaps as an advantage over speech, they also resemble meaning. The form of iconic gestures may evoke different meanings in different contexts. For instance, tracing a circle with one's forefinger can suggest the image of a wheel, an opening in a wall, or an orbit of a planet. Iconic gestures can also represent abstract concepts and ideas (e.g. the circle gesture for the food cycle); these gestures are sometimes referred to as 'metaphorical' gestures (Mathias et al., 2021a; McNeill, 1992).

The phenomenon of gestures co-occurring with speech has been studied in several disciplines such as neuroscience, linguistics, psychology, robotics, and social sciences. These studies usually investigate speech and accompanying gestures as comprising a multimodal mode of communication and they aim to understand how the two modalities interact. Such research has revealed that gestures can communicate meanings more precisely and more directly than words alone (Kang & Tversky, 2016), and that gestures are not superfluous to speech but are essential integrated components of speech as they are "tightly intertwined" with speech "in timing, meaning and function" (Goldin-Meadow & Wagner, 2005, p.234). It has also shown that the brain is activated in a different manner when exposed to speech accompanied by gesture than by the same speech alone (Willems et al., 2007), that gestures facilitate comprehension (Kang & Tversky, 2016) and production of speech (Abner et al., 2015; McNeill, 2014), that gestures lighten cognitive load (Jarbou & Abu Guba, 2022; Kita, 2000; Goldin-Meadow & Wagner, 2005), and that gestures help to disambiguate language (Holle & Gunter, 2007).

Co-speech gestures also provide meaningful syntactic, semantic, and pragmatic information during communication (McNeill, 1992; Goldin-Meadow & Wagner, 2005; Vainiger et al., 2014; Ozyurek, 2012; Dick et al. 2009). The contextual pragmatic properties of gestures are evident when we consider the relation between gestures and their social communicational context. Holler and Beattie (2003, p.130) believe that "gestures assist speech and facilitate the communication process" as a response to communicational demands in context "and for which the speaker considers the verbal channel as not sufficient" (see also Kendon, 1985).

In order to investigate the effect of co-speech gestures on learning in general and on learning a foreign language in particular, it is necessary to understand how speech and accompanying gestures are related and how gestures can support and facilitate language comprehension and production.

Neural Integration of Utterance and Gesture

Recent research in the fields of cognitive psychology and brain sciences supports the view that gestures and spoken language reflect a "common cognitive architecture" as "two parts of a single entity" (Xu et al., 2009, p. 20664) and that they originate from the same principal cognitive representation (De Ruiter et al., 2012, p. 245).

For many neuroscientists, the link between speech and gesture is neural since they are processed by common regions in the brain (Kelly et al., 2009); that is, the comprehension of words and accompanying co-speech gestures activates overlapping neural networks such as inferior frontal and posterior temporal brain regions (Xu et al., 2009; see also Schippers et al., 2010). Recent studies making use of 'functional Magnetic Resonance Imaging' (fMRI) have shown that Broca's area (classically associated with language processing) and Wernicke's area (classically associated with action) are connected by a bundle of nerve fibers referred to as the 'arcuate fasciculus' (Bernal & Altman, 2010). This indicates that there is a strong link between language processing and action, such as gesture, in the human brain (Willems et al. 2007; Holle & Gunter 2007; Kelly et al., 2004). Broca's area has a role not only in language production and comprehension but it has been proposed that it also plays "a functional role in the recognition, imitation, and production of actions" (Skipper et al., 2007, p. 262, see also Rizzolatti & Craighero, 2004). Such findings in neuroscience provide neural evidence to support the claim in behavioral psychology (McNeill, 2000, 1992; Kendon, 2004) that speech and gesture are highly interconnected in real life. However, these two parts of a single entity are not conceptualized simultaneously since gestures are conceptualized before conceptualization of accompanying speech (Hostetter et al. 2007, p. 332).

Moreover, the semantic functions of words and co-occurring gestures are not usually the same; gestures are not a repetition of the meaning conveyed by words as they can convey information not found in accompanying speech (Goldin-Meadow & Wagner, 2005, p.240). This seems to apply more to iconic gestures that can convey information about size, length, force, location, and intensity. For instance, the utterance, "she bought a big watermelon" can be accompanied with hand gestures representing the size of the referent. The descriptive information that is represented in the gestural embodiment of the 'big watermelon' does not exist in the utterance.

The above-mentioned findings that confirm the integration of speech and co-speech gestures into a composite unit of communication suggest that gestures can have a significant role in relation to language perception, production, and learning.

Co-speech Gestures and Language Perception

Gestures can facilitate perceptualization, learning, and understanding in many tasks including conversation and sentence memory (Mathias et al., 2021a; Kang & Tversky, 2016). Gestures co-occurring with speech help adult learners remember the meanings of new words in a foreign language (Kelly et al. 2009), and gestures can help disambiguate the meanings of ambiguous words (Holle et al., 2012; Biau et al., 2016). Kelly et al. (1999, p. 588) found that deictic and iconic gestures have a "powerful impact on how people comprehend and remember pragmatic communication."

Neuroscience studies give evidence that neurological brain activity during the perception of speech combined with gestures increases in brain regions associated with language processing more than when a communicative act is not accompanied with gestures (Schippers et al., 2010; Dick et al. 2009; see also Holle et al. 2008). This, perhaps, is a major reason why co-speech gestures can enhance comprehension and perception (Kelly et al., 1999), attention to the speaker's

communicative behavior, and recollection from memory (Mathias et al., 2021a; Kelly et al., 2009).

Co-speech Gestures and Language Conceptualization: The Information Packaging Hypothesis Abundant evidence exists that co-speech gestures not only benefit the addressee but also cognitively benefit the speaker. For instance, beat and iconic gestures were "found under both visibility and non-visibility conditions" (Wagner, 2014, p. 214; see also De Ruiter et al. 2012), blind speakers would gesture when talking to other blind people (Iverson and Goldin-Meadow, 1998), and babies would use co-speech gestures (Choi et al., 2021; Morford & Goldin-Meadow 1992; Yu et al., 2005; Acredolo & Goodwin, 1988). These findings strongly suggest that gestures have an innate role in speech production (Wagner, 2004).

Some of the most prominent findings concerning the processes of speech conceptualization and their connection with co-speech gestures are those related to the 'Information Packaging Hypothesis' (IPH) (; Wagner, 2014; Hostetter et al., 2007; Kita, 2000; Alibali et al., 2000). According to the IPH, "speech and gesture interact at an earlier stage when information is packaged, organized, and distributed across the modalities" (Wagner, 2014, p. 216). Research that is focused on the IPH shows that the decision to use co-speech gestures happens during the conceptualization stage of speech production (Kita, 2000). When there is a need for more conceptual processing, on the side of the speaker, gestures are more used than in situations involving easier or simpler conceptualization processing (Kita & Davies, 2009). This points out that gestures may be involved in the conceptualization of speaking (Kita & Davies, 2009; Melinger & Kita, 2007). These results suggest that speech and gesture productions are inherently linked during the preverbal processes of conceptualization.

According to the IPH, gestures seem to have a role in preverbal conceptualization during speaking, and speakers subconsciously gesture more when explaining 'difficult-to-conceptualize' information than when explaining 'easy-to-conceptualize' information (Kita, 2000; Hostetter et al., 2007; Abner et al, 2015). In other words, an increase in cognitive difficulty, mostly associated with the selection, organization, and articulation of ideas, leads to an increase in the production of co-speech gestures. Relevant research in cognitive psychology has concluded that gestures help speakers since they facilitate thinking and remembrance (Abner et al., 2015; Mayer et al., 2015; Goldin Meadow & Wagner, 2005) and because they add necessary complementary and supplementary information (Macedonia, 2014; McNeill, 1992) to utterances.

Gestures Decrease Cognitive Load during Speech Conceptualization and Production

One of the implications of the IPH is that speakers use "gesture to explore possible ways of organizing information" during conceptually complex situations (Alibali, 2005, p. 321). Since it has been found that congenitally blind speakers used gestures even when talking to blind participants, this suggests that the purpose of co-speech gestures is not to "solely convey information to the listener" (Iverson & Goldin-Meadow, 1998, p. 228). Goldin-Meadow et al. (2001) believe that gesturing lowers cognitive load and so facilitates thinking (see also Kang & Tversky, 2016; Goldin-Meadow & Alibali, 2012); Goldin-Meadow and Wagner (2005, p. 238) also discovered that speakers remember more when gesturing than when not gesturing (see also Mathias et al., 2021a)

Gestures seem to do this in relation to different processes: gestures help speakers manage the conceptualization demands involved in expressing thoughts (Hostetter, et al. 2007), gestures also "visually depict or highlight things" (Kelly et al. 1999, p. 578) and are a reflection of the imagistic cognitive representations that are present at the moment of producing speech (McNeill, 2014). Language cannot be separated from imagery, and gesture is the natural form of imagery with language (McNeill, 2014). A mental image is embodied in the spatio-motor space within the immediate environment of the speaker and it seems that this activity makes it easier for the

speaker to describe and explain processes that are depictions of mental images in his/her brain.

When "verbally expressing complex ideas, information needs to be linearized into small chunks, each of which can be verbally encoded in a clause. Gesture facilitates this process" (Kita et al., 2017, p. 251). According to Kita et al.'s (2017) 'Gesture-for- Conceptualization Hypothesis', co-speech gestures have self-oriented cognitive functions that are important for the activation, manipulation, and packaging of information in speaking and thinking. The IPH holds that "producing gestures helps speakers organize and package visuospatial information into units that are compatible with the linear, sequential format of speech" (Goldin-Meadow & Alibali, 2012, p. 258). Gestures also "increase the activation of lexical items and make them easier to be cognitively accessed (Krauss et al. 2000). In addition, when motor systems in the brain are engaged in language processing, participants "are generally faster to make semantic and lexical judgments" (Hostetter & Alibali, 2010, p. 246).

The IPH perspective that gestures help speakers in conceptualizing speech has been supported by a variety of research results. For instance, gestures add integrative, supplemental, or complementary information (e.g. shapes and motions) to speech (Mathias, 2021a; Repetto et al., 2017; McNeill, 1992), speech and co-speech gestures are synchronous (Esteve-Gibert & Guellai, 2018), speakers produce gestures even in situations when the addressee cannot see them as when talking on the phone or when solving problems silently (Chu & Kita, 2011). Co-speech gestures provide cues to the addressee to participate in enhancing the communication environment as they "may engage the listeners and provide better alignment between listener and speaker, improving speech processing and information encoding (Biau et al. 2016, p. 136). Gestures are also used when a speaker feels the need to resolve problems in communication, such as when there is a high chance of ambiguity, since gestures would increase the 'communicative effectiveness' of speech (De Ruiter et al., 2012, p. 245).

We can conclude that gestures participate in, and so facilitate, the conceptualization and production of a message. Gestures become more constructive in speech situations demanding more thinking and planning with regard to selection and arrangement of ideas, word choice, sentence structure, and perhaps even voice tone and pitch.

Focusing, Linearisation, and Cognitive Load

We can assume that some mental activities are more mentally difficult than others are with regard to generating thoughts, sorting them, ordering them, connecting them, and selecting the adequate words, sentences, and tone to express them to achieve the intended purpose of the communicative event in context.

According to Levelt (1989), speech production can be generally divided into three stages: conceptualization, formulation, and articulation (Levelt, 1989). Levelt (1989) divides the conceptualization stage into two subcomponents: macroplanning and microplanning. Macroplanning, in turn, is characterized by two processes: 'focusing' and 'linearization' (Levelt, 1989). 'Focusing' generally refers to which information to keep and which to ignore; 'linearization' refers to organizing information in a coherent order. In the formulation stage, the propositional form is linguistically (i.e. semantically, syntactically, morphologically, and phonologically) encoded and then is articulated. As Levelt (1989) explains, these higher demands are the major cause for increase in 'cognitive difficulty'. Thus, we can assume that if a spoken message is accompanied by a higher number of iconic gestures than other types of messages, then the high number of gestures indicates higher demands on 'focus' and 'linearisation' during the conceptualization of that message.

Cognitive difficulty of a task has been investigated from different perspectives in relation to gesture production. Alibali et al. (2000) found that children produced more gestures during explanation tasks than during descriptive tasks. They argue that explanation is more cognitively demanding than description. Melinger and Kita (2007) found

that gesture production increased when there was a greater choice of competing representations of what to say and when the speaker is uncertain about what to express. According to Melinger and Kita (2007, p. 473), "the linearisation and the focusing components of conceptualization are tied to gesture production and that increased load on these components results in increased gesture production." Similarly, Hostetter et al. (2007) discovered that gestures increased when information was difficult to conceptualize. Jarbou (2020) found that visual aid accompanying speech production did not lead to a reduction in the rate of gestures produced by a speaker; he suggests that this finding shows that gestures do not merely repeat the meaning of words but rather aid the production of words.

In many situations, the rate of co-speech gestures is highly dependent on the content and nature of speech since the linearization and the focusing components of conceptualization "are tied to gesture production" (Melinger & Kita, 2007, p. 473). Another justification for the occurrence and increase of gestures during mentally difficult activities is that gestures help reduce cognitive load since cognitive resources would be given more "capacity to perform cognitive tasks"; gestures would take up or assume some load of the verbal effort to express meaning (Goldin- Meadow & Wagner, 2005, p. 237) since they supplement and complement meaning. Goldin-Meadow et al. (2001) describe how participants remembered more words when they gestured during their math explanations than when they did not (see also Mathias et al. (2021a), Cook et al. (2008)). Gesturing does not only reflect the speaker's cognitive state but also shapes that state by reducing cognitive load (Goldin-Meadow et al., 2001).

In short, cognitive processes, such as the linearization and focusing components of conceptualization, and memory retrieval are usually less burdened and more relaxed, and so enhanced, when speech is accompanied with gestures.

Method

Search Strategy and Data Extraction

This study is qualitative rather than quantitative. We searched the databases of PubMed and PubMed Central using the following terms: "gestures," "co-speech gestures," "gestures and learning," and "gestures and foreign language." We aimed to include studies that are clearly relevant to our study questions; we did this by screening the abstracts of all collected resources. Then we narrowed our search by categorizing the collected resources into ones that are mainly theoretical or ones that are mainly experimental (i.e. involving participants, stimulus, fMRI or similar techniques, and/or pretests and posttests).

Criteria for Inclusion

We classified the included studies into ones that are mainly related to describing co-speech gestures (e.g. what they are, their types), related to psychology, or related to neuroscience (these latter also sometimes depended on theories from psychology). The next step was to categorize the experimental studies into ones that focus on the effect of gestures on learning in general and ones that particularly focus on learning a foreign language. This last step depended on a full-text study of each of the categorized articles in order to be able to analyze and synthesize the findings in each category. After the exclusion of irrelevant studies, the number of resources that we included in our study was 61; these were relevant to the topic concerning the effect of gestures on learning and/or learning a foreign language. We also included another 9 studies that were relevant to describing gestures and their effects on cognition. The next section discusses the results of our analysis of the studies about the effect of gestures on learning/learning a foreign language.

Results and Discussion

This section mainly presents and discusses the results of our aim to synthesize the findings in cognitive psychology and neuroscience

concerning the effect of gestures on learning, in general, and on learning a foreign language, in particular. This section also synthesizes the findings that aim to explain how gesturing enhances learning.

Co-speech Gestures Support and Enhance Learning in General

Research in cognitive psychology shows that gesturing by the instructor and/or learner enhances cognition and memory retrieval for the learner. According to Goldin-Meadow (2010), gestures promote learning through their effects on communication with the learners in addition to their effects on his/her cognition. Most research in this area focused on teaching and learning mathematics concepts.

Thus, as gestures provide information about a learner's cognitive state, the instructor may modify the input given to the learner to provide him/her with the appropriate input to facilitate learning. Goldin-Meadow (2003) found that the mathematics teachers, in her study, changed their instruction depending on whether their students produced speech-gesture mismatches or matches when they interacted with learners who could not solve mathematical problems. Singer and Goldin-Meadow (2005) designated a lesson about mathematical equivalence. They found that the learners improved when the lesson contained both speech and gestures as two different modalities. Vaenzeo et al. (2003) came to similar findings after they studied young learners' results on tests of symmetry; learners who watched the lesson that included both gestures and speech achieved much better than those who viewed the lesson that included speech only.

Still within the field of teaching mathematics, Cook et al. (2008) worked with two groups of learners during mathematical equation lessons. One Group was trained to use speech and gesture when they solved the problems while the other group used speech only. Four weeks after the lessons, both groups were tested and it was found that the learners who spoke and gestured while answering their mathematical equations retained what they learned for a longer time than the group that did not gesture while solving the problems. Similarly, Broaders et al. (2007) asked one group of learners to move their hands as they solved equivalence problems while another group was asked not to move their hands. The results show that the first group produced new strategies that enhanced their learning in comparison to the other group that did not gesture during the time they solved their problems.

Cook and Goldin-Meadow (2006) offer one justification for how gestures can promote learning. They found that children who watched a lesson that included the two modalities of gesture and speech benefited more from the lesson because watching the teacher make gestures made the learners themselves gesture more than those learners whose teacher used speech only. This suggests that gesturing enhances cognition for the learner. These findings agree with the results of research in neuroscience that gestures increase brain activity for the speaker and the receiver and so lead to better cognitive performance (see Schippers et al., 2010; Dick et al. 2009). Beilock and Goldin-Meadow (2010) conclude that gestures introduce action into the mental information concerning problems and so problem solving becomes easier.

Outcomes of studies concerning the effect of gestures on learning also agree with the findings in research concerned with the IPH that gestures aid thinking and lower cognitive load (see Kang and Tversky (2016) and Goldin-Meadow and Alibali (2012)). Wagner et al. (2004) found that their participants remembered more issues when their explanations of the answers they gave to mathematical problems were accompanied with their own gestures than when they did not gesture. These findings indicate that gesturing gives more freedom to cognitive resources involving working memory as gestures take on some of the explanation tasks (Kang & Tversky, 2016; Goldin-Meadow & Alibali, 2012). Gestures seem to do this since they can convey information in a sensorimotor mode that cannot be expressed by speech alone (e.g. information about the size or motion of objects) as an auditory modality or by pictures as a sensory modality.

Gestures Enhance Learning of a Foreign Language

Our Review shows that research concerning the effect of co-speech gestures on learning a FL is still limited. In fact, Gullberg (2014, p. 1872) mentions that empirical research that actually investigates the effect of gestures on FL vocabulary learning is "rare." In the last decade, however, research in this area, stimulated by advances in neuroscience and neuroimaging, has been gaining more and more momentum. This section of the study aims to investigate recent findings about the use of co-speech gestures as a means to enhance the experience and efficiency of learning a FL.

In spite of the many developments in FL teaching, many of the methods and techniques of teaching and learning still follow traditional methods to teach different aspects of a FL. For example, though vocabulary learning is one of the most prominent aspects of learning a FL, FL words are still taught depending on memorization of these words and translations in the learners' first language (usually as bilingual lists); these words are repeated until they are memorized (Repetto et al., 2017; Mathias et al. 2020a). Recent research in neuroscience and psychology has started to investigate the benefits of other methods of teaching and learning that focus on how the human brain processes FL production and reception (Mayer et al., 2014).

One of the problems concerning learning vocabulary in a FL is that learners tend to forget some words after a short time. The findings of several studies in cognitive psychology and neuroscience suggest that observing iconic gestures improves word recall. Repetto et al. (2017) compare the effects of two different types of 'enrichment' on learning and recollection of words in a FL. They discuss the difference between learning vocabulary by memorizing bilingual word lists, by enriching vocabulary learning with pictures, or by enriching vocabulary learning with gestures. A distinctive feature of their study is that it focuses on the learning of abstract, rather than concrete, words since they believe that these are more difficult to memorize. The results show that learners who produced self-performed gestures during the learning of new FL vocabulary made less errors in recalling this vocabulary than the group whose learning of vocabulary was enriched with pictures only. These results confirm that 'enactment' (production) of gestures, associated with the meaning of new FL words, can be used as one of the teaching strategies to improve learning and memorization of abstract words.

Similarly, in a study by Macedonia et al. (2011), the participants were native speakers of German and the FL words they learned were generated according to Italian phonotactics. One group learned the words with iconic co-speech gestures and the other learned the words with meaningless gestures (irrelevant movements that did not match the co-occurring words). Analysis of fMRI results of the learners' brain activity showed that iconic gestures that matched the learned words improved memory performance while the meaningless gestures did not have such an effect. Their findings indicate that iconic gestures that match the 'underlying representation' of the meaning of spoken words, rather than just any observed movements, improve recall of words in a FL.

Mathias et al. (2021a) aimed to test previous findings that the motor cortex aids in learning words of a FL when this learning is accompanied with gestures, as sensorimotor enrichment. Their results suggest that gesture-enriched foreign words were represented in the motor-cortex during training and these representations facilitated remembering the foreign words.

Multisensory Learning and Gestures

One of the recent neuroscience theories of learning is the 'multisensory learning theory'. This theory focuses on the enhancing effects of sensory 'enrichment' on learning. The theory explains that these benefits are achieved since the sensory effects would activate specific brain areas to process these effects (Mayer et al., 2015).

To test this theory, Mayer et al. (2015) used fMRI to observe the brain activity of their

participants who were asked to translate foreign words. Mayer et al. (2015) studied the brain activity of the learners in relation to each word that they heard. Mayer et al. (2015) enabled the researchers to recognize that different areas of the brain were activated depending on the type of sensory enrichment and also depending on the presence or absence of enrichment. They found that the 'visual-object-sensitive lateral occipital cortex' was activated when learning was accompanied with pictures. Increased activity in the 'biological motion superior temporal sulcus' (bmSTS) was associated with translating words that were learned with gestures. Their findings suggest that enrichment with gestures, self-performed ones in particular, is more efficient than learning with pictures and these two types of enrichment are better than using no enrichment when learning FL words.

Mathias et al. (2021b) replicated the study of Mayer et al., (2015) in their aim to further investigate the effect of gestures on learning FL vocabulary. However, Mathias et al (2021b) use a different technique of data collection than that of Mayer et al. (2015). They believe that techniques that use functional neuroimaging are limited to demonstrations of correlational effects. However, Mathias et al. (2021b) aim to investigate the casual effects that gestures can have on learning, and so they use 'transcranial magnetic stimulation' to study if sensory brain areas casually benefit FL learning that is aided with gestures. Their findings confirm those of Mayer (2015) that the same brain area (in this case the bmSTS) was activated during the translation of foreign words that were learned with gestures. This brain area was not activated during the translation of words learned with picture enrichment only. But Mathias et al. (2021b) have another important finding which is that the bmSTS aided the recall of the meanings of the foreign words, both concrete and abstract ones, that were learned during the gesture sessions even after five months. Their findings suggest that the learning of a FL in general and the retrieval from long-term memory, in particular, can be enhanced by using co-speech gestures since these deepen the representation, and add to, the neural web of the meaning of a word.

Macedonia (2014) argues that gestures that co-occur with learning FL vocabulary "create embodied representations of those words." Vocabulary learning is usually one of the most prominent aspects of learning a FL. Such an activity involves remembering the form (i.e. spelling and pronunciation) and meaning of new vocabulary. Tellier (2008) found that pre-school learners whose first language is French memorized English better when their learning was accompanied with gestures.

Similar memory-enhancing effects of co-speech gestures were also discovered by other studies. For instance, Naomi Sweller et al. (2020) found that motor imagery in the form of co-speech gestures enhance learning FL words. The students in this study were native speakers of English and they were divided into three groups; all groups were presented with Japanese verbs alongside their English translations. In one group, students heard the words with no gestures, in the second one, they heard the words alongside the presenter's gestures and in the third group, the students heard the words accompanied with the instructor's gestures and also reproduced the instructor's gestures. Sweller et al. (2020) found that the FL experiences were enhanced only for the group that observed and the one that observed and reproduced gestures. In another study of gestures and FL, Macedonia (2014) argues that gestures that co-occur with learning foreign language vocabulary produce embodied depictions of those words. Vocabulary learning is usually one of the most prominent aspects of learning a foreign language. Such an activity involves remembering the form (i.e. spelling and pronunciation) and meaning of new vocabulary. Tellier (2008) found that pre-school learners whose first language is French memorized English better when their learning was accompanied with gestures. Mayer et al. (2015) also found that learners of new vocabulary who paired new words with iconic gestures achieved better than those who paired the learning of new vocabulary with pictures.

In a similar study involving native speakers of English, Morett (2018) found that production of iconic gestures improved recall of Japanese words. The positive effects of gestures on FL learning relate to different aspects of a FL. Gulhareva and Prieto (2017) investigated the effect of observing beat gestures on the learners' performance concerning prosodic prominence of words. The learners were native speakers of Catalan learning Chinese as a FL. The instructor in this study produced rhythmic beat gestures relevant to the words that had the highest prosodic prominence. The results showed that learners who observed gestures achieved much better results concerning tone identification and word learning in Mandarin Chinese than the learners who were not shown beat gestures. These results suggest that producing co-speech gestures has a stronger effect on memory than just observing gestures during the learning of a FL.

How do Gestures Enhance Learning of a foreign Language?

Recent developments in neuroimaging and neuroscience have contributed to another development in recent research that aims to investigate the effect of gesturing on learning a FL. This development concerns the aim to understand how gestures enhance learning and memory retrieval concerning a FL.

Research in neuroscience found that gestures accompanying learning of FL words activate specific areas of the brain that are associated with movement (Macedonia et al., 2011; Kelly et al., 2009; Xu et al., 2009; Schippers et al., 2010). In another line of research, it has been found that memory retrieval is enhanced as the learners who use gestures during learning of vocabulary would be activating a cognitive motion image associated with the word they are learning (Mathias et al., 2021a; Kelly et al. 2009; Macedonia et al., 2011). Findings in this area reveal that a word exists in the brain as a network of interconnected sensory experiences. Thus, the motion representing accompanying the uttering of 'drink' would activate a mental image of drinking in the network of brain areas controlling movement and would also activate an image of the word itself in those areas traditionally associated with language processing (Broca's and Wernicke's). Therefore, gestures accompanying the learning of new words would aid in strengthening the trace of these words in the mental web of experiences concerning each word (see Barros-Loscertales et al., 2012). Dudschig et al. (2014) found that the components of the mental representation of a word in a FL, accompanied with gestures, activated sensorimotor traces in the brain of the participants similar to those activated by words in L1. The assumption here is that L1 words are usually acquired in contexts involving the natural use of language that involves involuntary gesturing by native speakers. This suggests that, during learning, gestures accompanying FL words would enhance memorization and retrieval of such words since these gestures add to the network of mental experiences associated with many words. Based on their findings, Dudschig et al. (2014) suggest that learning a word in a FL would be much enhanced if that learning involves sensorimotor events related to that word; they explain that this practice would make the learning of a FL word similar to the acquisition of L1 language that is usually associated with naturally occurring sensorimotor experiences for each word. Dudschig et al. (2014) also suggest that the words in a FL might be associated in the brain with experiences related to the referents of words acquired in L1.

Conclusion

The analysis of the synthesized data concerning the effect of gestures on learning shows that co-speech gestures accompanying the teaching and/or learning of a foreign language, in general, and of FL vocabulary, in particular, enhance learning. This positive effect is quantitative and qualitative; learners remember more FL words and they retain them for a longer time than when traditional methods of learning a FL are used. The sensorimotor aspect of gestures improves the representation of a word in the learner's brain since it beneficially adds to the interconnectivity of the auditory, sensory, and motor representations, of

a word, that are associated with various brain areas. However, relevant research in both of cognitive psychology and neuroscience focuses mainly on FL vocabulary learning and retrieval. As for further research, we suggest investigating how gestures can enhance the learning of several aspects and skills related to FL learning, such as reading, writing, and listening. Another type of research can compare one type of gestures (e.g. iconic) with another type (e.g. beat gestures) in order to test if one is more effective in learning a FL than another or if any of them is more effective in relation to one aspect of FL learning than another.

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