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ABSTRACT *Past literature shows that the brain regions involved in the understanding and production of verbal languages are the same brain regions that allow one to communicate in sign language. Brain lesion studies have confirmed that both spoken and signed language rely on a common system of neural and cognitive mechanisms. Further research has confirmed that by acquiring sign language skills at a young age, children have the advantage of enhanced cognitive processes pertaining to language, spatial reasoning, and attention. Future research could be conducted regarding the advantages that sign language acquired early in life could have on minimizing both the learning and attention disabilities in hearing and deaf children.*

Language is a critical component of survival and success for the human race. Using language allows people to express their ideas, thoughts, and feelings. Language gave people the opportunity to organize into societies and to learn from surrounding cultures in order to progress intellectually and socially. Research comparing dissimilar languages leads to insights concerning how the brain processes language and how acquiring a different language could be advantageous to cognitive development (Cattani, & Clibbens, 2005).

Sign language is composed of manual hand movements and facial expressions that convey thoughts, emotions, ideas, and information. Sign language has been in use by deaf individuals for centuries, and researchers today have proposed that the use of manual language preceded the development of proper written and spoken language (Lane, p. 45). Sign language is not manual English but is instead a language consisting of its own specific rules for grammar and structure. Sign language is often considered inefficient or incomplete by those who are unaware of its utility, but it allows the deaf community to enjoy a culture of rich language and communication comparable to that of the hearing community.

Examining the use of sign language by deaf and hearing people provides information about how our brains react in both different and similar ways when using sign language versus spoken language. Comparing the two types of language reveals which brain systems and functions are used to maintain the capacity to speak or sign. It will also clarify which systems are used to understand, define, and remember information within each language. When comparing neural activity in subjects communicating with either signs or verbal speech, the brain pathways and regions that are used to produce, comprehend, and analyze language have been found to be the same (Hickok, Bellugi, & Kilma, 2002). Although these similarities confirm that one language is not superior to the other in regards to communication abilities, it has been found that sign language has the power to enhance specific cognitive functions, especially in young children. These cognitive functions include attention, visual discrimination, and spatial abilities (Cattani, & Clibbens, 2005).

Brain Regions Involved in Language

Our ability to produce and understand language lies in many different areas of the brain. To effectively compare the neural pathways of spoken and signed languages, it is necessary to be familiar with the basic brain regions that are found to have considerable involvement in the production of language. The left hemisphere of the brain is strongly involved in the functions of language. This system involves Broca's area and Wernicke's area connected by the arcuate fasciculus.

Broca's area is found in the left frontal-temporal lobe. It is involved in speech production and coordinating movements of the mouth and surrounding areas. This area holds the information a person needs in order to physically produce words in a comprehensible manner and to combine words together into phrases and sentences. Although this area of the brain is considered to contain the 'motor memory' of speech, damage to it can produce many debilitating effects. Broca's aphasia causes deficits such as agrammatistm, anomia and difficulties with the articulation and pronunciation of words (Harrison's Manual of Medicine; Carlson, p. 396-398).

Wernicke's area is found in the left-temporal lobe of the auditory association cortex. This area is specifically involved in the understanding of speech, including speech perception and memories of particular sounds. Those who suffer from Wernicke's aphasia are able to hear speech, but they do not recognize or comprehend the words which are being spoken. This phenomenon is called pure word deafness. Though the speech of those who suffer from it may not be impaired, sufferers have great difficulty communicating because they do not understand what others are saying to them (Harrison's Manual of Medicine; Carlson, p. 399-400). This deficit has been found to involve mirror neurons which give important feedback about muscular, physical, and spatial movements. These include even very subtle movements that facilitate language production and aid individuals in understanding speech through visual cues.

Neurological Involvement in Sign Language

Hemispheric Lateralization

It has been found that the left hemisphere of the brain and the important brain regions that are involved in producing spoken language have the same amount of involvement in producing sign language. These areas of the brain, and their ability to perform their specific functions, develop independently of the persons' ability to hear. Thus, these areas are equally involved in language production for both deaf and hearing people. For example, Hickok, et al. (2002) made surprising discoveries in which damage to specific regions of Broca's area and Wernicke's area had comparable impacts on the ability of both signers and speaking individuals to produce comprehensible language. Those with damage to Broca's area had deficits in the production of the signs necessary to convey their thoughts, while those with Wernicke's area damage had difficulties in understanding and comprehending others' signs. Because of the dually important role of being able to produce and understand the different languages, information regarding the relationship between these two processes now allows analysis of how these areas develop in deaf and hearing people independent of their ability to hear. The independent development of these areas and their involvement in language shows that they are still in use in the brains of deaf people, just as they are in hearing people. The brain will be organized comparatively regardless of the way one produces and understands language (Hickok, et al., 2002). The ability to use language develops laterally in the left hemisphere in both speakers and signers, yet it has been found that sign language also incorporates the right hemisphere in a specialized way during production and comprehension of language.

Sign language does involve the right hemisphere to a larger extent than spoken language for spatial analysis and reasoning. Spatial analysis is one's ability to comprehend the relation of the physical aspects of signing and its relation to space, as well as the signs relations to one another. The ability to analyze spatial difference is important for signers in order to detect changes in the meanings of words. It was found by Bellugi, Kilma, and Poizner (1988) that damage to the left hemisphere of signers showed problems in the ability to produce and understand signs, but it did not affect their ability to effectively analyze visuo-spatial information involved in sign language. The opposite was found for signers who had damage to the right cerebral hemisphere. These signers showed deficits in spatial analysis but not in their ability to produce or understand signs. Because there is more cognitive involvement through the visuo-spatial analysis of sign language, the two cerebral hemispheres serve as compliments to one another in order to effectively monitor visuo-spatial aspects as well as to produce and comprehend sign language.

The Mirror Neuron System

Another important aspect of language has been found to be used in spoken and especially in sign language. The mirror neuron system of language, found primarily in Broca's area, is activated by major hand movements (as in sign language) and also by subtle muscular movements of the face during speech production (Carlson, pg. 408; Rizzolatti et al., 2004). Rizzolatti, and Craighero (2004) found that the mirror neuron system gives primates the ability to learn and understand through imitation. These neurons are activated both when performing a physical movement and when watching another individual making movement involved in speech production or body language. Because of the brain's vast involvement in all types of movement and comprehension, the mirror neuron system is found all throughout the brain and so makes lesion studies very difficult. Therefore, an experiment was done by Umilt'a, Kohler, Gallese, Fogassi, and Fadiga (as cited in Rizzolatti, & Craighero, 2004) in order to test the efficacy of the mirror neuron system in analyzing others' physical actions. The experimenters presented two visual tasks for monkeys as their mirror neuron systems were monitored. The first task gave the monkeys a full visual field where the experimenter reached for a piece of food. The second restricted the monkeys' visual field as the experimenter reached for a piece of food hidden behind a screen. In both trials, the mirror neuron system was activated in both the hidden and full-view conditions. This illustrates that the mirror neuron system is involved in action understanding even when there are merely physical cues about what is happening in the environment.

The mirror neuron system gives humans, primates and other animals the astounding ability to imitate actions with ease. The mirror neurons pick up visual cues performed by others and translate them into independently performed actions. During speech language acquisition, subtle facial cues, which are informative about how specific sounds are produced, play a major role in the development of speech abilities. In sign language acquisition, the mirror neuron system plays an even bigger role because of the nature of larger physical hand, arm, body, and facial movements involved in signing and expressing ideas physically. The mirror neuron system is activated by these physical movements and allows individuals to understand the physical aspect of language production. Therefore, this system plays a significant role in the acquisition of both speech and sign language.

Sign language and speech production consistently use the same brain pathways and systems in order to produce and understand language. The involvement of Broca's area, as well as Wernicke's area, and the influences of the mirror neuron system in both sign language and speech, signifies both major overlap in brain functioning and that the brain comprehends the drastically different languages in very similar ways. Willems and Hagoort (2007) also reviewed research confirming that these systems are used in both speech and sign production. Furthermore, communicating with sign language involves other brain regions such as the parietal cortex and the right cerebral hemisphere to enhance spatial analysis. Looking at a different field of research that involves brain injuries and lesions provides additional evidence that both modalities of language use similar brain systems.

Brain Lesion and fMRI Studies: Sign Language and Speech Share Brain Regions

Peperkamp and Mehler (1999) cited multiple studies that had been done by researchers involving deaf individuals with brain damage or cerebral lesions. Hickok, Bellugi, and Kilma (2002) studied native signers who had experienced brain trauma or lesions to the left hemisphere. They displayed aphasic type problems while producing sign language, unlike individuals with right hemisphere damage (as cited in Peperkamp, & Mehler, 1999). Those with left hemispheric damage consistently displayed language problems regardless of their ability to hear or their preferred method of language. Cerebral damage to the left hemisphere showed similar deficits in hearing and deaf individuals, emphasizing that the Wernicke's and Broca's pathways are involved in both speech and sign production.

An experiment performed by Buchsbaum, Pickell, and Love (2005) examined working memory in deaf individuals perceiving and producing signs. Sets of three nonsense signs were presented to the participants and they were then asked to reproduce the signs covertly. During the covert production of the viewed signs, the left hemisphere showed substantial involvement. Because of the left hemisphere's involvement in language and production, this finding is consistent with language produced verbally. Yet, during the viewing and perceiving period of the nonsense signs, fMRI scans showed bilateral brain involvement in both the temporal and parietal lobes (posterior STS, and posterior parietal cortex). This is unique to deaf and signing people. It suggests modality-specific effects in working memory for perception and production of language. However, the similarity between languages (frontal lobe involvement and left hemisphere dominance) suggests a modality-independent system of working memory. These findings point to plasticity, a theory which is the idea that speech-related processes that are not in use by those who are deaf are compensated for and devoted to sign-related processes. This accounts for the differences in cerebral involvement in language perception. Although the auditory input is absent, cerebral involvement for other purposes relating to sign language encourages cognitive enhancements not experienced by hearing and speaking individuals.

The Power of Sign: Enhancing Brain Development and Cognitive Functions

Although sign language and speech use the same brain pathways and regions to understand and produce language, the plasticity involved in sign language acquisition and the involvement of many other cognitive abilities allows the speculation that sign language can enhance cognitive functions in both hearing and deaf individuals. According to this hypothesis, the acquisition of sign language, especially at an early age, will incorporate the use of brain areas involved in attention and visuo-spatial abilities and will allow for cognitive enhancements during critical language and developmental periods.

It has been found that motor and language development are closely related and that motor developments are most often made before that of significant language developments (Bonvillian, Orlansky & Novack, 1983). This is consistent with the frequent finding that even if a child is hearing, it would be expected that developments in visuo-motor abilities, such as gesturing or signing, would be made before vocal expressions of language (Marshcark, 1997, p. 93). In fact, it was found by Bonvillian, Orlansky, and Novack (1983) that children of deaf parents produced recognizable signs 2-3 months earlier than a child would be expected to speak their first word. This early acquisition, along with the aforementioned right hemispheric involvement for sign language comprehension and spatial analysis, has been found to have an enhancing influence on several aspects of learning and memory.

It has been suggested that those who use sign language still have the dominating language functions found in the left hemisphere and that the right hemisphere is also involved in their mode of communication. Cattani, Clibbens, and Perfect (2007) used mixed groups of hearing and deaf participants—both signing and non-signing—to analyze their ability to remember and discriminate between abstract shapes and well known objects. The pictures were alternatively presented to either the right visual field or the left visual field. The results revealed that the deaf individuals had better memory for the abstract shapes than did the hearing individuals. Their ability to remember the well known objects were equivalent, yet the hemispheric domination differed. For deaf individuals, lateralization was found in the right hemisphere whereas the hearing individuals lateralized in the left hemisphere. Deaf individuals consistently incorporated the right hemisphere for analysis and memory of visual information as well as the incorporation of the left hemisphere for comprehension and production of language.

Cattani and Clibbens (2005) also found that when presented with a visual stimulus the ability to remember its previous location was superior in deaf signers. The individuals were presented with a visual stimulus of a circle on a black screen twice consecutively. The participants were then asked to determine if the stimulus was presented in either the same or different location. The deaf signers were consistently faster at recognizing differences in location and also showed right hemisphere domination when analyzing the categorical information. The hearing individuals again showed left hemisphere domination. Thus Cattani et al. (2005) confirms that sign language uses the right hemisphere as a compliment to the left hemisphere for visual discrimination and memory of visual stimuli.

Capirci, Cattani, Rossini, and Volterra (2000) found that sign language also enhances cognition in children who are not deaf. Capirci et al. (2000) conducted two experiments involving first and second grade children. The first experiment was a longitudinal study, including two independent groups. The first group consisted of hearing children taking a sign language class during the year (specifically Italian sign language, or LIS), and a control group consisted of hearing children not participating in any sign language classes. The Raven PM 47 test was administered at the beginning and end of the year to track cognitive abilities. The first sets of test scores between the two groups were comparable, but by the end of the year the students who had been learning LIS performed significantly better than their peers on visual discrimination and spatial memory tasks. Thus, incorporating sign language education during the early years of hearing children may help with their ability to analyze spatial and visual information.

Future Research

Considering the research that has been done, a longitudinal study spanning twenty or more years would be beneficial to further understand the systems of language comprehension and production between different languages. An examination of the cognitive processes that are involved could also lead to insights about how different modes of language use similar systems within the brain. This could be done through a longitudinal study used to assess brain development in relation to what areas are dominant in language acquisition independent of sound involvement. A study like this, using both deaf and hearing children who are learning either sign language or speech, would facilitate research on this topic.

The information that sign language enhances cognitive development in children and that of which brain areas are involved in both speech and sign, paves the way for future research. The uniqueness of a lengthened longitudinal study would add to the research on this topic because it has never been examined before and it would give insight to cognitive developments occurring later in life. Further research has the potential to discover the benefits sign language would have in enhancing cognitive functions pertaining to language. Other possible effects of sign language could be discovered in decreasing learning disabilities and attention deficits of early childhood. It has been discussed that sign language can enhance cognitive skills such as attention and spatial abilities, and perhaps the acquirement of sign language in early years could minimize a child's susceptibility to develop attention and learning disabilities.

Conclusion

The literature confirms that the brain pathways and regions that are involved in understanding, producing and analyzing verbal communication are the same regions involved in signed languages. Studies of brain damage and lesions to these areas will also manifest the same effects whether the individual uses spoken or signed language. These findings clarify that sign language is not a replacement for spoken language but is equivalent in the amount of cognitive involvement for processes concerning language such as comprehension and production. Sign language was, in fact, found to enhance specific cognitive abilities and brain development in young children who acquire sign language skills (whether deaf or hearing) in their early years.

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