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Hemisphere dominance: sign language aphasia and sign language processing

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Hemisphere dominance for language seems to be a basic fact of human psychology. This may be related to supramodal representation of natural language systems. Alternatively it might be associated with transmodal processing and convergence being a prerequisite for human speech. The fact that sign languages and sound languages are based on different primary modalities (visual-spatial for sign languages and oral-auditory for sound languages) provides the opportunity to compare the neurofunctional substrate of both language types in order to approach this problem. Empirical evidence can be taken from studies of sign language aphasia as well as from imaging studies exploring intact sign language processing. Up to now most known data document left hemisphere dominance for intact and defective sign language functions. Thus, empirical evidence appears to reject the hypothesis of language dominance to be dependent on the oral-auditory modality alone. We present additional evidence from a new imaging study on the perception of written and signed lexemes in deaf and hearing volunteers.

Introduction

Within the last two decades neurosciences became more and more interested in sign language research. Since sign languages make use of visual-spatial modalities different from oral-auditory modalities in sound languages, a comparison of the hemispheric organization underlying the processing of both language types could help to find out more about the nature of left hemisphere dominance. Several studies of brain-damaged deaf signers have documented aphasia-like symptoms after left-brain lesions only, which lead to the assumption, that the left hemisphere is dominant for both, sound and sign language (Rönnberg et al., 2000). However, the precise nature of language dominance needs further clarification. Therefore it is discussed whether the left hemisphere might be generally predisposed for language processing, independent of in- and output modalities (predisposition-hypothesis), implying a supramodal representation of language in the brain (Poizner et al., 1987).[1] This is opposed to the assumption of hemisphere dominance being specifically developed for the in- and output-requirements of speech (modality-dependency-hypothesis) (McKeever et al., 1975).

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In the sixties, Geschwind and Levitzky (1968) argued for a restricted modality-dependency-hypothesis. They stated that the dominance of the left hemisphere for language functions relies on auditory input alone (auditory-input-hypothesis). This claim was motivated by anatomical asymmetries in the two hemispheres, as new evidence was provided for the planum temporale being larger in the left hemisphere than in the right (Geschwing & Levitzky, 1968). The planum temporale is located on the inner perisylvian surface of the posterior temporal lobe and thus represents interplay between areas associated with auditory functions (auditory association cortex) and speech-understanding (Wernicke's area). From this anatomical finding Geschwind and Levitzky (1968) concluded that auditory input is the major determinant for left hemisphere dominance. Consequently, sign language processing in congenitally deaf who never had access to auditory routes cannot be lateralised in the left hemisphere. Support for this claim came from early visual-half-field-studies (VHF-studies), which demonstrated no or only minimal half-field asymmetries for the processing of signs in deaf signers (McKeever et al., 1975; Manning et al., 1977). Later VHF-studies disconfirmed this negative finding by showing a right half-field advantage similar to the one found for processing written words, indicating dominance of the contra-lateral left hemisphere for both, sound and sign language (Corina et al., 1992; Grossi et al., 1996; Panou & Sewell, 1984).[2]

Another variant of the modality-dependency-hypothesis is related to output-modality. Kimura argues for a specialisation of the left hemisphere for motor programming in general (motor-programming-hypothesis) and assumes that linguistic impairment is secondary to disorders in motor programming and execution of speech (Kimura et al., 1976; Kimura, 1993). Kimura's statement is based on the assumption that the processing of speech relies on segmental and sequential processing, which is essential for motor programming and is specialized in the left hemisphere. For sound language, Kimura's view appears to be supported by the clinical finding that disorders of motor programming (apraxia) are commonly associated with disorders of language (aphasia) (De Renzi et al., 1966; Poeck, 2000; Huber et al., 2000).[3] However, patients with aphasia do not always present with apraxia, even in the acute phase (Papagno et al., 1993), which is at variance with Kimura's assumption. Simple dissociations between aphasic and apractic disorders do not only hold for limb movements and oral movements, but may characterize the speech output directly. On the one hand, the selection and sequencing of articulatory gestures may be affected as a result of specific disorders in programming speech movements (speech apraxia). On the other hand, phonological encoding of lexical items may be affected on a supramodal level of processing leading to segmental errors in the production of sound structures both in speaking and writing (phonemic paraphasias/paragraphias). In the speech of aphasic patients, phonemic paraphasias may be present without any additional sign of speech apraxia, such as over controlled execution of articulation and/or difficulties of initiating articulation (Huber et al., 2000). Again, this makes Kimura's claim less plausible.

Of course, disorders of sign language after brain damage are another important area to study Kimura's attempt to relate language processing closely to motor programming. Sign language studies might be specifically revealing, as the observation of hand movements in linguistic and non-linguistic performance of deaf patients is more directly observable than phonological encoding, articulation and non-verbal oral movements in hearing patients. The motor programming hypothesis would have to be clearly rejected, if there were evidence for a double dissociation between sign language disorders (aphasia) and deficits in motor programming of non-linguistic hand movements (apraxia). With respect to localization, the motor-programming-hypothesis predicts a left lateralisation for sound as well as sign language functions because both are subordinated to motor programming, which is to be located in the left hemisphere.

A third variant of the modality-dependency-hypothesis refines Kimura's idea by assuming a specialization of the left hemisphere for rapid sequential processing (temporal-processing-hypothesis) (Tallal et al., 1995). This is required for both motor programming and auditory analysis of the speech input. The temporal-processing-hypothesis is derived from the importance of temporal cues for speech perception (Lisker & Abramson, 1964). In many studies, Tallal and co-workers presented evidence that both, children with language deficits and adult aphasics are not only affected in the processing of rapid acoustic cues in speech, such as voice onset time (VOT), but are generally impaired in the processing of acoustic contrasts which are based on high temporal resolution (Tallal & Newcombe, 1978). Tallal has concluded that the capacity for processing of rapidly changing sequences of sensory and motor events is an essential prerequisite for language skills (Tallal et al., 1995). Left lateralisation of language may have evolved due to the capabilities of the left hemisphere to process temporal sequences. With respect to sign language, it is not clear how much temporal resolution is required for the perception and production of signs (Corina, 1999). In recent studies deaf and hearing subjects performed equivalent well on tasks assessing temporal processing skills (Poizner & Tallal, 1987), thus showing no strict correlation between auditory input modality and temporal sequencing abilities.

Summarizing the discussion on hemispheric specialization, the main positions are turned into predictions on how likely it is to find different lateralisation for sound and sign language processing:

- Same lateralisation is predicted by predisposition-hypothesis and motor-programming-hypothesis,
- different lateralisation by auditory-input-hypothesis and temporal-processing-hypothesis (if sign language processing requires lower temporal resolution than sound language processing).

There are two main approaches to study hemispheric organisation of sign language processing. One is the examination of linguistic and non-verbal motor skills of deaf native signers with unilateral brain-damage of either the left or the right hemisphere. The symptoms are analysed and correlated with the anatomical site of the lesion. The second method investigates intact sign language processing by the help of functional brain imaging.

Evidence involving brain lesion data

In 1943 Leischner for the first time documented a breakdown of linguistic abilities in a deaf signer after a unilateral left-brain lesion caused by stroke (Leischner, 1943). Later on, several more single cases of sign language aphasia were reported (Rönnberg et al., 2000; Poizner et al., 1984; Poizner et al., 1987; Hickok et al., 1996; Hickok et al., 1998). The case reports show expressive symptoms on every level of the language system (syntactic, lexical and sublexical). The error patterns in signing appear to be independent of problems related to motor execution of hand- and arm-movements. Rather the aphasic symptoms of signing are strikingly parallel to well known expressive aphasic errors in sound languages and reflect difficulties and breakdown of central language processing (Rönnberg et al., 2000; Poizner et al., 1987; Huber et al., 2000; Huber & Ziegler, 2000). In both speaking and signing, the aphasic errors must be distinguished from difficulties of motor execution. Such difficulties arise from motor disease due to bilateral pathology (e.g. Parkinson's disease) and are documented for deaf signers as well (Poizner et al., 1987; Poizner & Kegl, 1992; Brentari et al., 1995).

No double dissociation between signing aphasia and hand movement apraxia is reported in the literature whereas some studies demonstrate simple dissociations between signing aphasia and motor programming disorders (apraxia) (Poizner et al., 1987; Poizner & Kegl, 1992; Leischner, 1943; Poizner et al., 1984). These are cases of deaf signers who suffer from sign language disorders but show no apractic errors in non-verbal hand movements. There is one controversial case in which apraxia and sign language aphasia were present together four years post left hemisphere stroke (Kimura et al., 1976). When the patient was retested six years later, he was completely recovered from apraxia but still suffered from a severe aphasia (Poizner et al., 1987).

Language comprehension is similarly affected in aphasia of both sign and sound languages. There are two common aspects. First, the receptive symptoms differ from expressive symptoms in quality as well as in quantity (Poizner et al., 1987; Huber et al., 2000; Huber & Ziegler, 2000). Second, comprehension errors are influenced by grammatical, lexical and sublexical similarity contrasts, e.g. there is confusion of subject-object relationship, of semantic class membership and of distinctive features in sublexical structure (Poizner et al., 1987; Huber et al., 2000; Huber & Ziegler, 2000).

In all case reports on sign language aphasia, the lesion affected those anatomical sites within the left hemisphere which are well documented in studies of sound language aphasia: posterior and anterior language areas, perisylvian opercula, insular cortex and basal ganglia (Rönnberg et al., 2000; Poizner et al., 1987). The resulting aphasic disturbances can be delineated from non-aphasic symptoms in signing just as in speaking. In particular, aphasic signing was demonstrated to be different from limb apraxia, even though both disorders result from left hemispheric lesions. After right hemisphere stroke, deaf signers were observed to have deficits in general visual-spatial capabilities such as hemineglect but not in linguistic processing even when spatially encoded features of sign language were examined (Poizner et al., 1987).

Evidence involving imaging studies

Early studies of intact sign language processing have involved visual-half-field-methods (McKeever et al., 1975; Manning et al., 1977; Corina et al., 1992; Grossi et al., 1996; Panou & Sewell, 1984) and Wada-testing (Mateer et al., 1984). Recent progress was made by imaging techniques such as Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI). These techniques allow detecting changes in regional Cerebral Blood Flow (rCBF) while a person is carrying out a task, thereby uncovering those brain regions, which show increased activation needed for the executed function. Söderfeldt et al. (1994; 1997) described similarities in processing sign and sound language for hearing children of deaf parents. The children were bilingual in Swedish Sign Language (SSL) and spoken Swedish. In the experiment, they had to comprehend unfamiliar novel texts, which were either received in video-taped spoken Swedish or in videotaped SSL. Both languages activated classical language areas of the left hemisphere rather than right parietal regions as was expected for signed texts by the authors.

MacSweeney et al. (2001) documented extensive activation of left Broca's and Wernicke's area and their right homologues in deaf signers during the perception of sign language sentences and single signs of British Sign Language (BSL). McGuire et al. (1997) investigated the "inner signing" (mental imagery of signing) in five deaf volunteers with primary competence in BSL. They demonstrated activation of left inferior frontal cortex (Broca's area). Again there was no activation in classical visual-spatial areas of the right parietal cortex. Shibata & Zhong (2001) also examined the inner signing and speech (sentence generation in American Sign Language (ASL) and English stimulated by line drawings of objects) in bilingual deaf signers and hearing non-signers. They found dominance of the left inferior and medial frontal gyrus for inner signing in deaf participants. In addition they described activation in the left perirolandic hand-area, which they interpreted as a "manual Broca's area".

Neville et al. (1998) documented the participation of classical language areas within the left hemisphere for hearing speakers of English (non-signers), deaf native signers of ASL and bilingual natives (spoken English and ASL). Subjects received sentences and pseudo-lexemes in their respective native language. However, the language areas were not activated, when non-signers perceived signs, nor when deaf signers received written English. This was interpreted as evidence for the linguistic system being only activated when participants processed stimuli of their respective native language. As additional information, Neville and co-workers assessed for their deaf subjects the grammatical competence in Standard English, which was examined through pre-experimental testing. Comparing the test-results with the activations during the fMRI examination revealed that those deaf subjects who scored high in the grammar-tests (= high grammatical competence for written English) displayed left hemisphere activation including Broca's area and Wernicke's area even for processing sentences in written English whereas all deaf participants without left lateralisation for written sentence-processing had scored very low in the grammar-tests. There is an obvious conclusion to these parallel findings. Activation of the left hemisphere language system mirrored the participants' grammatical competence for the language in question.

Processing of written and signed lexemes: A Functional Imaging Study

In order to compare the processing of both language types, we studied the rCBF in deaf and hearing subjects perceiving written and signed lexemes. By choosing written rather than spoken stimuli we were able to keep the peripheral input condition for the two language types as comparable as possible.

Subjects: The study included 10 prelingually deaf males, ranging in age from 22 to 43 years, with primary competence in DGS (= Deutsche Gebärden Sprache/German Sign Language). The control-group consisted of 10 hearing males, matched in age and education, with no competence in DGS. All subjects were right-handed.

Methods: The tasks were the same for both groups: Hearing as well as deaf participants were asked to read written words and to watch videotaped signs. The stimuli were linguistically as parallel as possible in both tasks. We selected high frequent concrete nouns with simple structure (no compounds) in both languages. In DGS all consisted of non-transparent signs[4]; in written German their length varied between four and nine letters.

Imaging was done with a Philips 1.5 Tesla Gyruscan NT with standardized birdcage head coil using a multishot T2* weighted gradient echo EPI sequence with the following parameters: TR = 3000ms, TE = 50ms, FA = 90°, FOV = 192, Matrix = 64x64, slice thickness = 5 mm, ISI = 3s, number of scans per run = 88 (+ 2 initial dummy scans). Each scan consisted of 35 contiguous slices parallel to the AC-PC line covering the whole brain without gap.

Image analysis was performed using statistical parametric maps (SPM99; Welcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm). All images were realigned to the first image of each subject and normalized according to Talairach and Tournoux (1988).

As scanning paradigm we chose a block design with alternating on- and off-periods. There were three sessions, each consisting of four on- and four off-periods. The stimuli were projected via a mirror system onto a screen attached to the head coil. In off-periods the subjects had to fixate a centred cross on the screen. There were three experimental conditions (one condition per session): written lexemes flashed on the screen as a whole, videotaped signs, written lexemes presented as running words. The running word condition was chosen in order to control for the movement component of signs. Therefore words were presented letter per letter running from the right to the left with standstill on the screen until the whole word was assembled in central position. In all three conditions - static written words, videotaped signs, and running written words - the presentation time of each stimuli was approximately three seconds.

Results and Discussion: In both groups the visual perception of static words resulted in an expected bilateral occipital activation of primary visual cortex (BA 17), bilateral activation of occipito-temporal areas (semantic system) (BA 19/37), bilateral activation of the frontal operculum (BA 47) and bilateral activation of the frontal eye-field (FEF (Paus, 1996)) (BA 6/8) (Figures 1 and 2). Surprisingly, there was strong activation in left Broca's area (BA 45) in deaf participants only (Figure 2). As in most previous studies, no involvement of Broca's area was found for hearing subject. Apparently, passive reading was not demanding enough. Activation of Broca's area was previously found only when the task implied conscious decision making such as phoneme-monitoring, word-generation, word versus pseudoword decision or semantic categorization (Price et al., 1994). Therefore we may assume for the deaf participants of our study that passive reading was rather demanding and required more conscious linguistic processing than in the hearing group, which consequently activated Broca's area. This interpretation implies left hemisphere dominance for (written) language in the deaf subjects.

The high linguistic demands might be due to poor education and low familiarity with written material. Another explanation comes from reports the participants gave immediately after the experiment. Each participant was asked what kind of strategies he used during the task. Nearly all deaf participants (nine out of ten) reported that they had mentally activated signs when they perceived written lexemes. Therefore the activation of Broca's area might be due to inner signing. Independent evidence for such activation can be found in previous studies (McGuire et al., 1997; Shibata & Zhong, 2001).

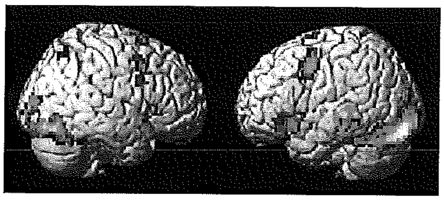

Fig. 1[5]. Passive perception of written lexemes (static presentation) in hearing participants

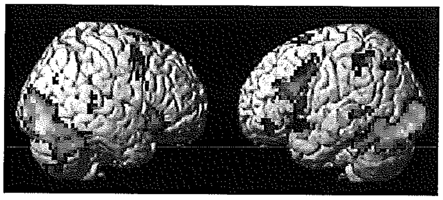

Fig. 2. Passive perception of written lexemes (static presentation) in deaf participants

For passive perception of signs, we found striking differences between the two groups. Hearing participants showed extensive bilateral activation of occipital-temporal and prefrontal areas (Figure 3). In deaf subjects the prefrontal activation was limited to the operculum bilaterally and to Broca's area (BA 45, left) (Figure 4). Overall their left hemispheric activation pattern was similar although weaker to the one found for reading static words, revealing left hemisphere dominance for language irrespective of language types. The weaker activation most likely reflects the fact that perceiving signs is more natural and therefore less demanding for deaf signers. The activation pattern in hearing participants reveals no lateralisation to Broca's area

(Figure 3). They showed extensive bilateral prefrontal activation reaching from frontal operculum (BA 47) up to FEF (BA 6/8). Most likely, this reflects general problem solving strategies. Apparently the hearing subjects tried to interpret the significance of the signs by conceptual guessing[6]. Therefore the bilateral occipital activation extended into temporal and - to a lesser degree - into parietal areas recruiting conceptual knowledge of the so called where- and what-system (Ungerleider & Haxby, 1994). In the deaf participants mainly superior and middle temporal areas were activated, stronger on the left than on the right, indicating that their processing was more focussed on the meaning of lexical items.

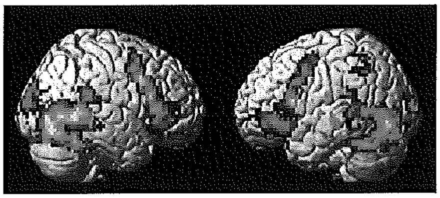

Fig. 3. Passive perception of sign lexemes in hearing participants

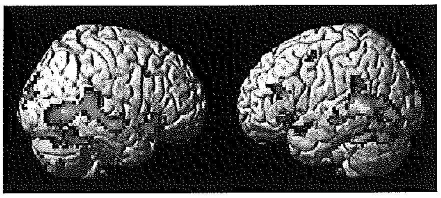

Fig. 4. Passive perception of sign lexemes in deaf participants

For dynamic words the activations found are very similar for both groups. Deaf as well as hearing participants show bilateral activations in occipital areas extending into parietal and temporal cortex as well as in prefrontal areas including Broca's area on the left (Figures 5 and 6). In comparison to static words and signs, the parietal activation was more pronounced, possibly indicating more intensive programming of spatial processing in this condition. No linguistic laterality was found in either group. Apparently processing the motion features of this task was overriding the linguistic demands.

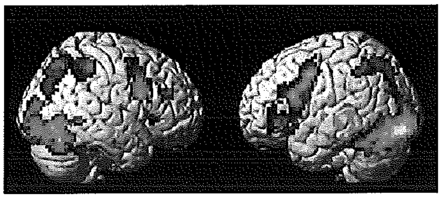

Fig. 5. Passive perception of written lexemes (dynamic presentation) in hearing participants

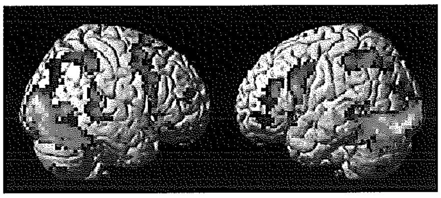

Fig. 6. Passive perception of written lexemes (dynamic presentation) in deaf participants

Conclusions

In summary, lesion data as well as imaging studies seem to support the assumption that competent users of sign language undergo a linguistic analysis involving the left hemisphere when perceiving signs. In our own study we demonstrated specific activation of Broca's area, which is in accordance with results of previous studies of sign language processing (Rönnberg et al., 2000). Most strikingly we were able to show activation of identical linguistic networks for processing signs and written words in the brain of deaf signers. Similar activation patterns were previously reported for hearing subjects when lexical decision-making was required (Price et al., 1994). Broca's area is always crucially involved. Thus, passive perception of both written words and signs seems to demand more active involvement in deaf subjects than passive word reading in hearing subjects.

Overall these findings clearly contradict the assumption of the auditory-input-hypothesis. Left hemisphere dominance does not seem to be determined exclusively by the oral-auditory route. Future research will have to clarify to what extend a linguistic predisposition of the left hemisphere has to be assumed or whether there are other options for the development of the specialization of the left hemisphere for language processing. The need for transmodal processing and convergence is certainly decisive for both, sound and sign language activities. Whether this is linked to specific verbal processing demands as assumed by the predisposition-hypothesis or to general non-verbal demands as postulated by the motor- and the temporal-processing-hypothesis remains to be seen. Our data demonstrate that the left perisylvian sound language system is also recruited in deaf signers for lexical recognition despite the lack of auditory input.

Nederlandse samenvatting

Het bestaan van een taaldominante hemisfeer lijkt een basisgegeven binnen de psychologie van de mens. Enerzijds zou dit in verband gebracht kunnen worden met een supramodale representatie van natuurlijke taalsystemen, anderzijds kan een transmodale verwerking van taalsystemen en een convergentie van de verschillende modaliteiten een basisvoorwaarde zijn van menselijke taal en spraak. Het feit dat gebarentalen en gesproken talen op verschillende modaliteiten gebaseerd zijn (de visueel-spatiële voor gebarentalen en de oraal-auditieve voor gesproken talen) geeft ons de kans dit probleem aan de orde te stellen door een vergelijking te maken tussen de neuro-functionele substraten van beide taalsoorten. Empirische evidentie kan worden ontleend aan studies over afatische gebarentaal en aan *imaging*-studies over de verwerking van gebarentaal bij een intact taalsysteem. Tot nu toe rapporteren de meeste studies een dominantie van de linkerhemisfeer voor intacte en aangetaste gebarentaalfuncties. De empirische evidentie lijkt zo de hypothese te verwerpen dat taaldominantie alleen afhankelijk is van de oraal-auditieve modaliteit. Wij presenteren hier een nieuwe vorm van bewijsvoering afkomstig uit een *imaging*-studie over de waarneming van geschreven en door gebaren aangegeven lexemen bij dove en horende proefpersonen.

Notes

1 It is worth to note that the predisposition hypothesis is motivated independently of the issue of sound and sign language: Language dominance in hearing subjects is not restricted to processing of speech alone but extends to written language processing as well. Damage of the left perisylvian language networks in hearing with competence in speech and written language regularly results in impaired processing of both language modalities. Furthermore, aphasic error patterns typically show supramodal features.

2 The stimuli varied across the studies in terms of movement. While early VHF-studies used static drawings of single signs as stimuli in the latter studies moved signs were chosen. Poizner and Kegl (1992) discussed this component to be responsible for the opposing results.

3 Apraxia without aphasia was reported in rare cases, mainly after right hemisphere lesion (Papagno et al., 1993).

4 We chose non-transparent signs in order to prevent the participants from conceptual guessing. Transparency of signs was evaluated in a pilot study. We presented 249 single DGS-signs to a group of 20 hearing subjects with no competence in sign language. They had to guess the meaning and rate their confidence in interpreting the sign on a five-point-scale separately for each item. A score of 1 denoted no transparency, a score of 5 high transparency. As an additional condition we showed the same signs to a small group of hearing controls familiar with DGS. They had to classify the signs into high, middle or low transparent signs. The signs that were eventually chosen as stimuli for the fMRI-study had to pass two criteria: First, they had to be scored 1 or 2 by at least 95% of the first group. Second, they had to be classified by all participants of the second group as low transparent signs.

5 All images show contrasts of activation versus rest-condition. In each figure the right hemisphere is represented on the left side and the left hemisphere on the right side. Significant activations are represented in red and yellow (SPM evaluation: cluster size = 5 voxels; p = 0.005, uncorrected).

6 Indeed all hearing subjects reported conceptual guessing when asked about their associations and strategies immediately after scanning.

References

Brentari, D., Poizner, H. & Kegl, J. (1995). Aphasic and Parkinsonian signing differences in phonological disruptions. *Brain and Language, 48*, 69-105.

Corina, D.P. (1999). On the nature of left hemisphere specialization for signed language. *Brain and Language*, *69*, 230-240.

Corina, D.P., Vaid, J. & Bellugi, U. (1992). The linguistic basis of left hemisphere specialization. *Science, 255*, 1258-1260.

De Renzi, E., Pieczuro, A. & Vignolo, L.A. (1966). Oral apraxia and aphasia. *Cortex, 2*, 50-73.

Geschwind, N. & Levitzky, W. (1968). Human brain: left-right asymmetries in temporal speech region. *Science, 161*, 186-187.

Grossi, G., Semenza, C., Corazza, S. & Volterra, V. (1996). Hemispheric specialization for sign language. *Neuropsychologia, 34*, 737-740.

Hickok, G., Bellugi, U. & Klima, E.S. (1996). The neurobiology of sign language and its implications for the neural basis of language. *Nature, 381*, 699-702.

Hickock, G., Kirk, K. & Bellugi, U. (1998). Hemispheric organization of local- and global-level visuospatial processes in deaf signers and its relation to sign language aphasia. *Brain and Language, 65*, 276-286.

Huber, W., Poeck, K. & Weniger, D. (2000). Aphasie. In: Hartje, W. & Poeck, K. (Eds.), *Klinische Neuropsychologie*. Stuttgart: Georg Thieme Verlag.

Huber, W. & Ziegler, W. (2000). Störungen von Sprache und Sprechen. In: Sturm, W., Herrmann, M. & Wallesch, C.W. (Eds.), *Lehrbuch der klinischen Neuropsychologie. Grundlagen, Methoden, Diagnostik, Therapie.* Lisse: Swets & Zeitlinger.

Kimura, D. (1993). *Neuromotor mechanisms in human communication.* Oxford: Oxford University Press.

Kimura, D., Battison, R. & Lubert, B. (1976). Impairment of non-linguistic hand-movements in a deaf aphasic. *Brain and Language, 3*, 566-571.

Leischner, A. (1943). Die "Aphasie" der Taubstummen. Ein Beitrag zur Lehre der Asymbolie. *Archiv für Psychiatrie und Nervenkrankheiten, 115*, 469-548.

Lisker, L., Abramson, A.S. (1964). A cross language study of voicing in initial stops: acoustical measurements. *Word, 20*, 384-422.

Manning, A.A., Goble, W., Markman, R. & La-Breche, T. (1977). Lateral differences in the deaf in response to linguistic and non-linguistic stimuli. *Brain and Language, 4*, 309-321.

Mateer, C., Rapport, R.L. & Kettrick, C. (1984). Cerebral organization of oral and signed language responses: case study evidence from amytal and cortical stimulation studies. *Brain and Language, 21*, 123-135.

MacSweeney, M., Woll, B., Brammer, M., Campbell, R., Calvert, G., David, A., Williams, S.C.R. & McGuire, P.K. (2001). Cortical correlates of lexical and syntactic sign language processing. *NeuroImage, 13*, 563.

McGuire, P.K., Robertson, D., Thacker, A., David, A.S., Kitson, N., Frackowiak, R.S. & Frith, C.D. (1997). Neural correlates of thinking in sign language. *Neuroreport, 8,* 695-698.

McKeever, W.F., Hoemann, H.W., Florian, V.A. & Van Deventer, A.D. (1975). Evidence of minimal cerebral asymmetries for the processing of English words and American Sign Language in the congenitally deaf. *Neuropsychologia, 14*, 413-423.

Neville, H.J., Bavelier, D., Corina, D., Rauschecker, J., Karni, A., Lalwani, A., Braun, A., Clark, V., Jezzard, P. & Turner, R. (1998). Cerebral organization for language in deaf and hearing subjects: biological constraints and effects of experience. *Proceedings of the National Academy of Sciences, USA, 95*, 922-929.

Panou, L. & Sewell, D.F. (1984). Cerebral asymmetry in congenitally deaf subjects. *Neuropsychologia, 22*, 381-383.

Papagno, C., Della Sala, S. & Basso, A. (1993). Ideomotor apraxia without aphasia and apraxia without aphasia: the anatomical support for a double dissociation. *Journal of Neurology, Neurosurgery and Psychiatry, 56*, 286-289.

Paus, T. (1996). Location and function of the human frontal eyefield: a selective review. *Neuropsychologia, 34,* 475-483.

Poeck, K. (2000). Motorische Apraxie. In: Hartje, W., & Poeck, K. (Eds.), *Klinische Neuropsychologie*. Stuttgart: Georg Thieme.

Poizner, I., Bellugi, U. & Iragui, V. (1984). Apraxia and aphasia for a visual-gestural language. *American Journal of Physiology, 246*, 868-883.

Poizner, H. & Kegl, J. (1992). Neural basis of language and motor behaviour: perspectives from American Sign Language. *Aphasiology, 6*, 219-256.

Poizner, G., Klima, E.S. & Bellugi, U. (1987). *What the hands reveal about the brain.* Cambridge: MIT Press.

Poizner, H. & Tallal, P. (1987). Temporal processing in deaf signers. *Brain and Language, 30*, 52-62.

Price, C.J., Wise, R.J.S., Watson, J.D.G., Patterson, K., Howard, D. & Frackowiak, R.S. (1994). Brain activity during reading. The effects of exposure duration and task. *Brain, 117*, 1255-1269.

Rönnberg, J., Söderfeldt, B. & Risberg, J. (2000). The cognitive neuroscience of sign language. *Acta Psychologica, 105*, 237-254.

Shibata, D. & Zhong, J. (2001). Internal sentence generation in the deaf: English and sign language. *NeuroImage, 13*, 601.

Söderfeldt, B., Ingvar, M., Rönnberg, L., Eriksson, L., Serrander, M. & Stone-Elander, S. (1997). Signed and spoken language perception studied by positron emission tomography. *Neurology, 49*, 82-87.

Söderfeldt, B., Rönnberg, J. & Risberg, J. (1994). Regional cerebral blood flow in sign language users. *Brain and Language, 46*, 59-68.

Talairach, J. & Tournoux, P. (1988). *Co-planar stereotaxic atlas of the human brain.* Stuttgart: thieme verlag.

Tallal, P., Miller, S. & Fitch, R.H. (1995). Neurobiological basis of speech: a case for the preeminence of temporal processing. *Irish Journal of Psychology, 16*, 194-219.

Tallal, P. & Newcombe, F. (1978). Impairment of auditory perception and language comprehension in dysphasia. *Brain and Language, 5*, 13-34.

Ungerleider, L.G. & Haxby, J.V. (1994). 'What' and 'where' in the human brain. *Current Opinion in Neurobiology, 4*, 157-165.