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Individual differences in the functional asymmetry of the human brain

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Abstract. Standard models of hemispheric asymmetry assume the dychotomous division of functional competence between the two hemispheres. Individual subjects, however, often do not fit such prototypical patterns and show great variation with respect to the functional differentiation of their hemispheres. The present paper rewievs the results of some our investigations on the effect of various subject related factors on brain lateralization. Among these individual experience, gender and handedness seem to be of most significance.

Key words: hemispheric asymmetry, individual differences, left-handedness, gender, development

INTRODUCTION

Since 1861 when Paul Broca provided the first direct evidence of functional differentiation of the two halves of the human brain (Broca 1861) this differentiation has attracted the attention of many authors who have accumulated great amount of behavioural, electrophysiological, anatomical, and even biochemical data confirming Broca's original observation about brain asymmetry (see Hugdahl 1988, Kitterle 1991, Hellige 1993 for recent reviews). This view was also confirmed by Sperry's investigations on split-brain patients who underwent transection of the corpus callosum, and of the other commissures connecting the two brain hemispheres (Sperry 1968, 1974).

Research on subjects with no damage to the central nervous system which followed Sperry's report provided further data (see Beaumont 1982, and Bryden 1982 for reviews) which were used to develop certain standard models of hemispheric asymmetry claiming that each hemisphere has its own characteristic domain of competence. It seems, however, that many individuals do not fit such standard asymmetry patterns. Hemispheric asymmetry is a statistical phenomenon as it can be found only in the majority and not in all tested subjects. The notion that the pattern of lateralization of brain functions varies depending on several individual factors gains more and more adherents. In his recent book J. B. Hellige states: "Individuals differ from each other in patterns of hemispheric asymmetry and in the ways that the two hemispheres interact. In the past, much of this individual variation was treated as random error and ignored. In fact, many of the individual differences are reliable..." (Hellige, 1993, p.4). In the present paper, the results of some our investigations related to the effect of various factors influencing brain lateralization are shortly presented.

HEMISPHERIC ASYMMETRY AND DEVELOPMENT

The first question to consider is whether the lateralization of functions in the brain changes with an individual's development. It is a question of great importance as it relates to the basic problem - whether the brain hemispheres already exhibit different functional properties at the moment of birth or, whether we are born with a symmetrical brain and the hemispheric asymmetries develop progressively with the development of all brain functions. In the literature, two basic approaches can be found. One of them derives from the idea of Lenneberg (1967) who proposed that all functions, including that of speech, develop initially in parallel in both hemispheres. Both hemispheres are thus initially equipotential as regards their capability of acquiring speech and other functions. In ontogenesis those functions undergo gradual lateralization (Corballis and Morgan 1978) which becomes fully established only at adolescence (Miller and Turner 1973). Models of gradual lateralization commonly assume that this development strongly depends on environmental factors. The proponents of a developmental lateralisation concept often refer to clinical data showing that, when left hemisphere damage occurs early in life then, a child is able to achieve a relatively good proficiency in language skills, despite serious initial speech disturbances (Rasmussen and Milner 1977). Generally, it is assumed that the earlier the damage takes place the more promising can be the prognosis for rehabilitation.

Other authors argue that the hemispheres are functionally differentiated at the moment of birth (Witelson 1987, Bradshaw 1989, Hellige 1993). "Cerebral asymmetry almost certainly does not develop; asymmetries, morphological and behavioural, are present *ab initio*, and the most that can be said is that they may unfold" (Bradshaw 1989, p. 192-193). This point of view is supported by findings of hemispheric differences in evoked potentials to speech sounds in infants (Entus 1977, Molfese and Molfese 1980). It is further supported by anatomical data showing that some asymmetries in the structure of left and right hemispheres found in adults are already present in infant and fetal brains (Geschwind and Levitsky 1969, Witelson and Pallie 1973).

Developmental changes in brain functional lateralisation as an effect of child experience have been investigated in our laboratory. Jabłonowska and Budohoska (1976) presented children with laterally exposed letters. Children 5 year old, who did not know the letters were selected for the experiment. Thus, the letters constituted for them meaningless patterns. The same children were tested later at the age of 7 years at a time when they had started to read and write and knew the alphabet well. The children's task consisted of recognising letters presented briefly on a screen in the left or right visual field. The children responded by pressing one of four buttons denoting individual letters. The 5 year olds made a similar number of errors to letters presented in the right and left visual fields. On the other hand, the 7 year old children performed better in the right visual field i.e., when the stimuli were directed to their left hemispheres. These data suggest, therefore, that hemispheric asymmetry changes with age and depends on life experience.

The importance of experience in the formation of hemispheric asymmetry is also supported by investigations carried out by Szeląg et al. (1992a, b) on 14-year old congenitally deaf children. These children suffered from a considerable (80 dB or more) hearing loss which made it impossible for them to hear human speech, even if it was very loud. The experiment was to determine whether hearing deprivation which prevented deaf children from normal contact with speech influenced the functional organization of their brains. The children's task was to recognize laterally presented words, neutral faces or faces expressing positive and negative emotions. In the word recognition test, the results showed a left visual field/right hemisphere advantage in deaf children opposite to the right visual field/left hemisphere advantage found in those with normal hearing. In the face recognition test, there were no hemispheric differences in the congenitally deaf, whereas in the controls the right hemisphere dominated. These results suggest that lack of auditory experience influences the organization of functional hemispheric specialization. It seems, that the necessity to make use of visuo-spatial information in the process of communication causes right hemisphere dominance in verbal tasks. The involvement of the right hemisphere in language functions may influence the perception of other visuo-spatial or emotional stimuli.

Interesting investigations were also conducted on children with developmental desorders: dyslexia and stuttering. Szeląg et al. (1993) investigated hemispheric asymmetry in severe and mild stutterers, using a word recognition test. The data showed a left hemisphere superiority in the processing of words in both the mild stuterrers and the fluent speakers, but a right hemisphere advantage in the severe stutterers. The results point to a close relationship between the severity of stuttering and functional brain organization.

Our studies on lateralization of functions in dyslexic children (Kołtuska and Grabowska 1992) have shown that this reading disability can also be associated with atypical lateralisation of brain function. Children participated in a dichotic listening procedure consisting in recalling pairs of words presented simultaneously to the two ears. Two variants of the test which differed in attentional requirements were used: in Experiment I words were presented at a level of loudness typical for natural speech while in Experiment II they were presented at a low intensity level. The recognition scores for stimuli presented to the left and right ears were compared. In contrast to controls, who showed typical right ear advantage in both versions of the experiment, dyslexic children were highly sensitive to changes in experimental procedure which shifted cerebral dominance from one hemisphere to the other. The results of this study suggest, that hemispheric asymmetry is not a stable feature but may show some instability at least in a group of reading disabled subjects.

In the light of these data it seems that the question of whether asymmetry is an inborn brain characteristic or develops in an individual's life is not easy to answer. The thesis that some aspects of asymmetry are present at birth but functional lateralisation changes with age and depends on individual experience seems to best fit the existing data. This idea was expressed nicely by Joseph B. Hellige

(1993 p. 260): "Functional hemispheric asymmetries are shaped by the interaction of many biological and environmental factors, begining with the fetus as it develops *in utero* and continuing into old age". Whether this variability results from developmental changes in functional plasticity of the brain, as proposed in several recent publications (e.g. Bradshaw 1989, Hellige 1993), or from changes in hemispheric asymmetry *per se*, is a subject to further research.

THE EFFECT OF GENDER ON BRAIN LATERALIZATION

Many every-day observations as well as psychological data provide evidence that men and women differ in strategies and skills used in the performance of various tasks (Halpern 1986, Bradshaw 1989, O'Boyle and Hellige 1989). Those differences are already apparent in small children. Girls, as a rule develop speech ability much earlier than boys and they achieve great proficiency in it rapidly. Boys, on the other hand, master, at a relatively early stage, constructional skills and show an advantage in play and games involving these abilities (Maccoby and Jacklin 1974, Archer and Lloyd 1989). Likewise, adult men show superiority over women in many functions associated with spatial operations involved in such activities as direction assessment, orientation on a map, feeling of direction, constructional tasks or chess play (Harris 1981, Linn and Peterson 1985). On the other hand, women perform better in the domain of various linguistic activities (Harshman et al. 1983, Kimura 1992). Verbal fluency and mental rotation tests are two which show a most pronounced difference between men and women. In the former, the subject's task is to name as many words as he or she can which begin on a given letter. Women show a distinct advantage in this test (Kimura 1992). In the latter test the subject is presented with three-dimensional geometrical figures which are rotated in space. They are to be matched with one of two other figures. In this task men score much higher than women (Lim and Peterson 1985, Marino and McKeever 1989, Snyder and Harris 1993). As the functions involved in the performance of those tests are thought to be characteristic of left or right hemisphere processing modes respectively, it has been proposed that sex-related differences in cognitive functions result from different lateralization of those functions in women and men (Bufferey and Gray 1972, Levy 1974, Harris 1978, Inglis and Lavson 1981).

Most spectacular data concerning sex-related differences in the functional organization of the brain are provided by Mc Glone (1977) who found that aphasia resulting from the damage to the left hemisphere occurs three times more often in men than in women. It also occurs less frequently in men than in women due to the right hemisphere injuries. Although some authors argue that data provided by Mc Glone are too extreme (de Renzi et al. 1980, Kimura 1983a), nevertheless, much data support the view that speech is more related to the left hemisphere in men than in women (Hecaen et al. 1981, Bryden 1982).

Clinical data are used not only for the evaluation of the frequency of disturbances following unilateral brain damage but also for assessment of their specificity. For this purpose, the Wechsler intelligence test is used frequently. It consists of two parts: the verbal scale examines language functions, while the performance scale examines nonverbal functions such as the ability to reproduce a visual pattern with blocks. McGlone (1978) found that only in men did disturbances in verbal and performance scales depend on the side of lesion: as expected, left-side damage resulted in disturbances on the verbal scale whiles right-side injuries lowered scores on the performance scale. In women, the disturbances were less specific to the localization of the damage.

A similar relationship was established in our investigations concerning the effect of unilateral brain damage on perception of visual illusions such as the Mueller Layer illusion and the so called subjective contour illusion (Nowicka and Grabowska 1993, Nowicka et al. 1993). We found that left and right hemisphere damage differentially affected illusion perception in men: right-side damage disturbed patients' susceptibility to visual illusions while left side damage did not have any effect. For women, the disturbances of the perception of illusions resulted from both left and right hemisphere damage. It is also worth noticing that women show greater susceptibility to some illusions than men (Grabowska et al. 1991). On the basis of this kind of clinical data several authors have come to the conclusion that for both speech and visual-spatial functions, men show higher level of brain lateralization than women (Levy 1974, Butler 1984, Wood et al. 1992). This thesis gets some support from investigations carried out on healthy subjects with the use of electrophysiological and tachistoscopic methods (see McGlone 1980, Bryden 1982, Beaton 1985 for reviews). Although these investigations do not always reveal a significant effect of gender on measures of functional brain asymmetry, nevertheless, if such a relationship is established it usually points to higher asymmetry in men than in women (McGlone and Davidson 1973, Davidoff 1977, Piazza 1980). Moreover, electrophysiological investigation conducted by Grabowska et al. (1992) shows different processing dynamics in men and women when some spatial stimuli such as gratings are used. Visual evoked potentials to black and white square-waved gratings had greater amplitudes in the right hemisphere; those differences, however, appeared in earlier evoked potential components in women than in men.

Interesting investigations on the effect of sex on brain asymmetry have recently been conducted by A. Herman. She examined transsexuals, persons who show an incongruence between their biological sex and their self-declared gender identity, and two control female and male groups. In these investigations, besides the biological sex and gender identity, sex role identity (a certain set of psychological features characteristic of men and women) was taken into consideration. Transsexuals did not differ reliably from controls in the pattern of lateralization of verbal and visual-spatial functions (Herman et al. 1993). However, some more complicated sex related relationships were observed. In a test requiring identification of laterally presented words individuals with high feminity scores showed more pronounced left hemisphere advantage than those with high masculinity scores. In a grating recognition test higher lateralization index (right hemisphere superiority) was observed in these groups who show an incongruence between their biological sex and sex role identity (masculine females and feminine males). Thus, the results suggest that, although neither the biological nor the psychological gender determine the pattern of brain asymmetry, the interaction between those factors seem to be of importance for the formation of functional brain organization.

To sum it up, it can be stated that although some data support the thesis that the female human brain is less lateralized than that of males, the issue is very complicated and requires further investigations in which the dynamics of hemispheric asymmetry and the effect of social-psychological factors should be considered.

HEMISPHERIC ASYMMETRY IN LEFT-HANDERS

In the last part of this paper we discuss a question which attracts much attention from authors dealing with the lateralisation of brain functions, namely the question of left-handedness. We will try to answer the question of the relationship between handedness and brain asymmetry. One source of information in this field consists of clinical data, specifically, the effects of unilateral brain damage or the results of the Wada test (see Bryden 1982, Bryden and Steenhuis 1991, for review). Both sets of data allow the assessment of frequency of localization of verbal and visual-spatial functions in the left and right hemispheres. The results show considerable agreement. They indicate that structures controlling speech are more frequently localized in the left hemisphere than in the right one both in left-handed and right-handed subjects. The difference, however, is that in left-handers, right hemisphere or bilateral speech control is found more frequently than in right-handers. A similar relationship is also found as regards the localization of visual-spatial functions. In left-handers, only a slight prevalence of the right hemisphere is found; on the other hand, the frequency of localization of those functions in either the left hemisphere or in both hemispheres is relatively high.

These data find support from investigations on healthy persons who were exposed to laterally presented stimuli, both visual and auditory (Annet 1982, Kimura 1983b, Bryden 1988). However, bilateral localization of speech function is often accompanied by impaired performance of visual-spatial functions (Levy 1969). Moreover, some papers suggest the existence of an interaction between left-handedness and sex (Hecaen et al. 1981, Sanders et al. 1982). Results of our investigations are in agreement with such data. In a study by Marzi et al. (1988) the reaction times for size evaluations of angles presented to the left and right visual fields were measured. The investigation involved right-handed men and women and left handed men and women. According to our expectations, in right-handed subjects, a dominance of the right hemisphere was found, i.e., those subjects responded faster when stimuli were presented to the left visual field. In left-handed subjects either hemispheric equipotentiality (in men) or even an opposite-direction asymmetry was observed (in women). Thus, only in left-handed women was hemisphere dominance shifted from one side to the other. It is intersting to notice that the left-handed persons differed from right-handed ones only as regards the level of their right hemisphere functions. Both in men and women, the reaction times in left-handers were longer than in right-handers only for stimuli presented to the left visual field, i.e. those addressed to the right hemisphere.

Differences in lateralization of verbal processes between left-handed and right-handed individuals have been found in investigations by Czachowska--Sieszycka and Szeląg (1985). They examined a group of left-handed and right-handed women in a test which required making same vs. different judgements of laterally presented words. In left-handed women, the authors observed a right hemisphere predominance. The opposite was found for the right-handed women. Thus, the results confirm the notion that left-handedness in women results in a reversed pattern of brain lateralization.

A number of reports indicate that the corpus callosum plays a significant part in formation of brain lateralisation (Lassonde et al. 1981, Denenberg and Yutzey 1985, Hellige 1990, Cook 1992). Several studies were thus conducted to compare the volume of that structure in right and left-handers (Witelson 1985, Witelson and Kigar 1987, Clarke 1990, Habib et al. 1991). The original study by Witelson showed that the volume of the corpus callosum was, on average, 11% greater in left-handed than in right-handed persons. These results suggest that, in general, greater brain equipotentiality, found in left-handed persons, can result from better inter-hemispheric communication subserved by callosal fibres. Witelson's *post mortem* investigations were partly confirmed by MRI studies (Habib et al. 1991). Our recent electrophysiological investigation on right-handers (Nowicka et al. 1994) has shown that the time of information transmission from the hemisphere dominant for a given function to the non-dominant one differs from the transmission time in opposite direction. Our current investigations are designed to check whether this asymmetry occurs also in left-handed persons who, according to Witelson's research, should have stronger interhemispheric interconnections.

In general, the investigations on hemispheric asymmetry in left-handers support the view that, in many cases, functional organization of their brains differs from that found in right-handed subjects. Our investigations show that the effect of left-handedness also depends on subject's gender.

To sum up this short review of investigations on individual differences in the lateralisation of brain functions, it should be stated that the popular view, according to which all people are characterised by stable, unchangeable pattern of hemispheric asymmetry does not fit the existing data. Lateralization of functions in the human brain varies to some extent and depends on several factors, among which individual experience, sex and handedness are of the most significance.

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