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Asymmetry of the Human Posterior Parietal Cortex: Extrasulcal Morphometry and Multidimensional Analysis

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ABSTRACT

Introduction. We researched the morphometric asymmetry of the extrasulcal surfaces of the human posterior parietal cortex (precuneus-PEC and superior parietal lobule-SPL).

Aim of the study. Our aim was to examine potential asymmetries of the extrasulcal surfaces of the PEC and SPL with multiscalar analysis of surface, cortical thickness and neuronal volume densities using our previous morphometric data.

Material and methods. On 20 brains (40 hemispheres) of adults we measured the length of the hemispheres and extrasulcal surfaces of the PEC and SPL. The sum of value of hemispheric length and the sum of PEC and SPL extrasulcal surfaces obtained total numerical scores for potential distinct differentiation of brains with larger left or right hemispheres.

Results. Brains (15) with larger left hemispheres had average extrasulcal surfaces of SPL: left-15.04 cm^2; right 16.51 cm^2; of PEC: left 12.9 cm^2; right 10.15 cm^2. The average length of the left hemispheres in these brains was 17.23 cm, and the average length of the right hemispheres was 16.74 cm. The total numerical score for left hemispheres was 45.17, and for right hemispheres 43.40. In five brains with larger right hemispheres the average extrasulcal surfaces of SPL were: left 15.47cm^2; right 17.24cm^2; of PEC: left 12.02 cm^2; right 12.2 cm^2. In the brains with larger right hemispheres the average right hemispheric length was 17.4cm, and the average left hemispheric length was 16.9 cm. In this group the total numerical score for right hemispheres was 46.84, and for left hemispheres 44.39.

Conclusion. The obtained morphometric parameters clearly distinguished two groups of brains, majority (fifteen) with larger left hemispheres, and few (five) with larger right hemispheres. Also, our data indicate that human right precuneus deserves further careful studies by multiscale approaches.

Key words: human brain, morphometry, asymmetry, precuneus, superior parietal lobule

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Introduction

In the brains of our more recent ancestors posterior parietal region had over the last two million years especially increased in the size, with a major role of the parietal areas during human brain evolution, but the basic functions of the posterior parietal cortex (PPC) are conserved from rodents to humans.[1] Specializations of the visual system included new visual areas that contributed to a dorsal 'action' stream of visuomotor processing, from early visual areas to the greatly enlarged region of the PPC, which plays a critical role in the real-time control of action.[2]

During the evolution emerged specialization of the two hemispheres for the functions of speech, language and other impressive cognitive abilities.[1] Generally, the left hemisphere in majority of persons is responsible ("dominant") for verbal, linguistic, and analytic functions, for reading and writing, right handedness, rational and logical thinking.[3] Left hemisphere in 90-95% "right-handers" is usually speech dominant without relation to „handedness" of person.[4] The right hemisphere ("non-dominant") is responsible for visuospatial abilities, emotional behaviour, music functions, attention processes, for understanding of affective (nonverbal) components of speech, and facial expression.[5] The problem of brain asymmetry for speech and language is much more complex than usually reported, because of different genetic effects on symmetric and asymmetric brain structure[6], since hand dominance is also significantly influenced by regional asymmetries in parietal association and dorsomedial frontal cortices.[7] Right-hemisphere dominance increases with degree of handedness, from 4% (strong right-handers), 15% (ambidextrous),to 27% (strong left- handers)[9] and the females are more often "non-consistent right-handers".[8]

The posterior parietal cortex (PPC) includes the portions of the same region (Brodmann area- BA7), which comprises the greatest part of the parietal lobe, but also contains BA5,[9] and those are the precuneus (PEC) of medial surface and thesuperior parietal lobule (SPL)on dorsolateral surface. However, the cortex of PEC as the medial part of BA7 is not clearly defined by all authors as the PPC.[10]

There were numerous studies of morphological and functional asymmetries of human brain[11], but only few includedthePPC. After detailed parcelationseveral areas of SPL showed higher variability in the left hemisphere and/or in men, and few of them showed a hemisphere by- gender interaction.[11]

Recent imaging methods (functional MRI, diffusion tensor tractography, sophisticated software) opened new approaches to the investigations of the brain, including accurate cortical parcelation.[12] So, the concept of the default mode network (DMN) of brain, with components more active in rest than during task performance[12] requests new interpretations of old data. All posterior medial cortical clusters are congruently coupled with the DMN[13], and in the resting state persistsstrong functional connectivity among the PEC, posterior cingulate, medial prefrontal, lateral parietal cortex, and hippocampal formation.[14] However, within the DMN functional connectivity and grey matter volume are not equally distributed between hemispheres, and functional asymmetries are not always determined by structural asymmetries.[14]

Previously we published the results of macro-scale (surfaces), medium- scale (cortical thickness) and micro-scale (neuronal volume densities) researches of human PPC. The crossing of data from different scale studies can be useful, but approaches like this have not been applied so far. For example, at the macro-scale, the occipital cortex can be described as specialized for visual processing, at a finer scale, different occipital areas may be distinguished, and at an even finer scale, different visual sub-regions within areas may be dissociated.[15]

Aim of the study

The aim was to examine the asymmetries of the extrasulcal surfaces ofhuman PPC (PEC and SPL), with additional multiscalar analysis of surface, cortical thickness and neuronal volume densities using our previous morphometric data.

Material and methods

Researchof extrasulcal (visible) surfacesof PEC and of SPL included 20 brains (40 hemispheres) of adult persons (27-65 years, without visible pathological changes or neuropsychiatric history) and in accord with Helsinki Declaration.After removal, brains were perfunded by physiological saline solution, than by 10 % formaline, and there after were fixed by floating four weeks in the same solution.

After careful removal of meninges and vessels we firstly measured the legth of hemispheres and than the extrasulcal surfaces of the PEC and the SPL, all as the parameters determining the size of hemisphere, in order to eventually differentiate brains with larger left or right hemispheres. Hemispheric length (fronto-occipital distance-FO) is the distance paralell to the intercommissural line connecting the most prominent points of frontal and occipital lobes. Only if sum of all these parameters (FO + sum of PEC and SPL surfaces), as the total numerical score, was larger in one hemisphere, we defined that hemisphere as a larger one. This way we separated for the studyfifteen brains with larger left hemispheres and other five brains with larger right hemispheres.

Figure 1. A. Precunes; B. Superior parietal lobule; (lines indicate boundaries)

Morphometry of extrasulcal surface of PEC was perfomed by overlapping it by one transparent sheet in the midsagittal plane and the measurements of convex extrasulcal surfaces of SPL was performed with several transparent sheets[14] and final measurement was done by the use of milimetric paper. In statistical analysis we used methods of descriptive statistics and parametric T-test.

The data which in addition were re-analysied originate from our previous macro-scale studies of PEC surfaces[15], medium- scale measurements of cortical thickness of PEC and SPL[13] and micro-scale stereological study of numerical densities of fifth layer neurons in PEC and SPL.[14]

Results

Results of measurements of extrasulcal surfaces of SPL and PEC in brains with larger left hemispheres are presented on Table 1. and of brains with larger right hemispheres on Table 2. Differences between the values of left and right FO were not statistically significant (p> 0,05) in both groups of brains.

Table 1. Brains with larger left hemispheres (n=15)

	left SPL	right SPL	left PEC	right PEC
X	15.04 cm^2	16.51cm^2	12.9 cm^2	10.15 cm^2
Min.	11.69 cm^2	11.41 cm^2	8.31cm^2	9.08 cm^2
Max.	19.47 cm^2	20.41cm^2	16.9 cm^2	14.71cm^2
CV	15.2%	17.2%	14.7%	16.8%

SPL = Superior Parietal Lobule; PEC= precuneus

Table 2. Brains with larger right hemispheres (n= 5)

	left SPL	right SPL	left PEC	right PEC
X	15. 47cm^2	17.24cm^2	12. 02 cm^2	12.2 cm^2
Min.	11.19 cm^2	11.41 cm^2	10.19 cm^2	9.45 cm^2
Max.	19.3cm^2	20.82cm^2	15.26 cm^2	13.75 cm^2
CV	14.16%	16.5%	14.16%	14.59%

SPL = Lobulus parietalis superior; PEC= precuneus

Brains with larger left hemispheres had total numerical score of45.17 for left hemisphere, and for right hemisphere it was smaller - 43.40. Homogeneity of sample is confirmed by the low coefficients of variation (CV) for both sides (below 20%).

In group of other five brains with larger right hemispheres total numerical score for right hemispheres was 46.84, and for left 44.39. Both CV were practically the same and very low.

Discussion

Fronto-occipital distance (FO) as one of components of the total numerical score in determining of larger hemisphere is used for indirect estimation of the brain size and in archeological research of remnants of skulls. 16Finding of larger left FO values in group of 15 brains (left FO 17.23 cm; right FO 16.74 cm) is in accordance to the general findings of somewhat larger left hemisphere in different races and nations[15] and can be related to the majority of left hemisphere dominance (majority of right-handers), and to thelocalization of speech centers in left hemisphere.[11] Actually, the problem of differences in sizes of hemispheres is very complex, because in Caucasians left hemisphere was longer in 58.3%, the right one in 30.5% (we found 25%) and both hemispheres had equal lengths in 11.2% of cases.[14] Because the differences between the left and right FO values were not significant in both groups of brains, we introduced additional surface based parameter (sum of extrasulcal surfaces of PEC and SPL). The accuracy of this other used component of the total numerical scoreis confirmed by the findings that the major brain covariance pattern is strictly associated with the relative proportions of PEC and that the longitudinal proportions of the PEC are the main element in adult brain variability in the sagittal plane.[17] Even though

we did not have the data about hemispheric dominance in our autopsy study, analysis of the data from the literature,including available morphological studies, supports the use of the total numerical score for determining the larger hemisphere as the dominant one.

In our digital morphometric study (50 brains)[15], the values of extrasulcal surface of PEC in males and in females in general correspond to our findings for only right PEC in brains with larger right hemispheres. The significant difference of surfaces between the right PEC of males andof females[16] and greater decline with age in right PEC of males[17] also point to the right PEC. In brains with larger right hemispheres numerical density (Nv) of fifth layer neurons of right PEC was highly significantly larger than in left PEC.[18] In brains with larger left hemispheres it was kind of inverse relation of this, because of highly significantly thicker cortex of right PEC, which was not the case in the brains with larger right hemispheres.[13]

Our current and previous data undoubtedly confirm the finding of important differences between the groups of brains with larger left and right hemispheres, with special reference to the right PEC parameters.[13,15] Significant right-left asymmetries of the medial surface in posterior regions,the non-significant larger surface of right PEC, thicker cortex of left PEC in males with the absence ofcorrelation between the surface and thickness of cortex of PEC are in favour of this.[17]

PPC plays a critical role in fast decision making, sensory attention, motor intention, and/or working memory.[3] Visuospatial abilities are preferentially mediated by the right hemisphere, and the right human PPC strongly inhibits activity the contralateral one by direct transcallosal projections.[3] All posteriormedial cortex clusters were congruently coupled with the DMN.[17] While some authors exclude PEC from DMN, other state that PEC is the main node of DMN in human brains.[18] Precuneal cluster (attention and motor tasks) is also mostly connected to the right temporo-parietal junction.[17,18] Many of intrinsic functional brain networks are highly lateralized, and DMN is mostly left lateralized. The visual network is strongly right lateralized[4], indicating the right PEC. Unlike the right PEC, we found that the right SPL was greater in both groups of brains.

SPL is a sensori motor interface for visually guided movements[5] and billateral SPL have direct relationship to variability in perception[6] and in males have greater decline with age.[9] Significantly higher values of the cortical thickness and Nv in left SPL in brains with larger left hemispheres[5] correspond to the left - right asymmetry in cortical thickness of SPL.[9] The left SPL, which during the memory retrieval has greater activity when items are correctly identified as "old" versus "new"[7] had the greatest Nv among the all examined regions (PEC and SPL) in both groups of brains.[4]

The term "association cortex" does not describe a uniform entity because the degree of specialization varies considerably between regions of association cortex since the complex parietal zones can range from highly specialized to highly flexible, and SPL belongs to flexible regions.[18]

Because of the complexity and often time consuming MRI measurements we introduced a new combined parameter, total numerical score (FO+ the sum of PEC and SPL), for the determination of larger hemisphere on individual brain. It is obvious that the simple measurements of only one, or even of several parameters are not sufficient to provide accurate data about cortical asymmetries of human brain. Our combined multiscale approach is justified by the statement that the attribution of functional specialization may be considered at different spatial scales.[11] Our finding of proportionally larger group of brains with larger right hemispheres than of left-handers in population allows to speculate that some of these brains originated from the right-handers. Therefore, we expect that some predetermined functions of the right hemisphere can be more pronounced than in usual brains with larger right hemispheres, which is something that deserves further in- vivo studies.

Conclusion

Our results indicate that the future studies of brain morphology and function as well as of morphometric asymmetries of the brain must include the data on brain size, cerebral dominance, age, gender of persons involved in the study and that, if possible, it should be performed simultaneously in different, selected dimensions, i.e. bymultidimensional analysis.

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Asimetrija zadnjeg parijetalnog korteksa čovjeka: ekstrasulkusna morfometrija i višedimenzionalna analiza

SAŽETAK

Uvod: Istraživali smo morfometrijsku asimetriju ekstrasulkusne površine zadnjeg parijetalnog korteksa čovjeka (koru precuneusa-PEC i gornjeg parijetalnog režnjića – lobulus paarietalis superior- LPS).

Cilj rada: ispitati moguće asimetrije ekstrasulkusne površine PPC čovjeka (PEC i LPS), primjenom višeskalarne analize: površine, kortikalne debljine i volumenske gustoće neurona PPC korištenjem naših predhodnih morfometrijskih podataka .

Materijal i metode: Na 20 mozgova (40 hemisfera) odraslih osoba mjerili smo dužinu hemisfera i ekstrasulkusnu površinu kore PEC i LPS. Zbir vrijednosti dužine hemisfera sa zbirom površina kore PEC i LPS izrazili smo kao ukupni numerički skor za razlikovanje potencijalno veće lijeve ili desne hemisfere velikog mozga čovjeka.

Rezultati: Petnaest mozgova sa većim lijevim hemisferama imali su prosjek extrasulkusne površine kore LPS: lijevo 15.04 cm^2; desno 16.51 cm^2; PEC: lijevo 12.9 cm^2; desno 10.15cm^2. Prosječna dužina hemisfera ovih mozgova je na lijevim hemisferama 17.23 cm, a na desnim hemisferama 16.74 cm. Ukupni numerički skor za lijeve hemisfere bio je 45.17, a za desne hemisfere 43.40. Kod pet mozgova sa većim desnim hemisferama prosjeci ekstrasulkusne površine LPS bili su: lijevo 15.47cm^2; desno 17.24 cm^2; PEC: lijevo 12.02 cm^2; desno 12.2 cm^2. Kod mozgova sa većim desnim hemisferama prosječna dužina desnih hemisfera bila je 17,4 cm, a prosječna dužina lijevi hemisfera 16.9 cm. U ovoj grupi ukupni numerički skor za desne hemisfere bio je 46.84, a za lijeve hemisfere 44.39.

Zaključak: Dobijeni morfometrijski parametri jasno razlikuju dvije grupe mozgova, većina (petnaest) sa većom lijevom hemisferom, i manju grupu (pet) sa većom desnom hemisferom. Također, naši podaci ukazuju na to da desni precuneus čovjeka treba dalje pažljivo istraživati multiskalarnim pristupom.

Ključne riječi: ljudski mozak, morfometrija, asimetrija, precuneus, lobulus parietalis superior