Using the International 10-20 EEG System for Positioning of Transcranial Magnetic Stimulation

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Summary: Background: The International 10-20 system for EEG electrode placement is increasingly applied for the positioning of transcranial magnetic stimulation (TMS) in cognitive neuroscience and in psychiatric treatment studies. The crucial issue in TMS studies remains the reliable positioning of the coil above the skull for targeting a desired cortex region. In order to asses the precision of the 10-20 system for this purpose, we tested its projections onto the underlying cortex by using neuronavigation. Methods: In 21 subjects, the 10-20 positions F3, F4, T3, TP3, and P3, as determined by a 10-20 positioning cap, were targeted stereotactically. The corresponding individual anatomical sites were identified in the Talairach atlas. Results: The main targeted regions were: for F3 Brodmann areas (BA) 8/9 within the dorsolateral prefrontal cortex, for T3 BA 22/42 on the superior temporal gyrus, for TP3 BA 40/39 in the area of the supramarginal and angular gyrus, and for P3 BA 7/40 on the inferior parietal lobe. However, in about 10% of the measurements adjacent and possibly functionally distinct BAs were reached. The ranges were mainly below 20 mm. Conclusion: Using the 10-20 system for TMS positioning is applicable at low cost and may reach desired cortex regions reliably on a larger scale level. For finer grained positioning, possible interindividual differences, and therefore the application of neuroimaging based methods, are to be considered.

Key words: International 10-20 EEG system; Cortex anatomy; Stereotaxic neuronavigation; Transcranial magnetic stimulation.

Introduction

The International 10-20 system (Jasper 1958) is commonly used for EEG electrode placement and for correlating external skull locations to underlying cortical areas. In the last years, the 10-20 system has been increasingly applied for coil positioning in transcranial magnetic stimulation (TMS) studies. TMS has been established for studying non-invasively cortical information processing in cognitive neuroscience (Walsh et al. 2000), and its therapeutic potential in psychiatry and neurology is subject of intensive investigation (Wassermann and Lisanby 2001). These applications share the basic issue of a reliable positioning of the magnetic coil above a desired cortex region in order to influence the local neuronal activity by the induced electromagnetic field. The 10-20 system is conventionally based on the identification of anatomical landmarks like nasion, inion and preauricular points with consecutive placement of the electrodes at fixed distances from these points in steps of 10 or 20%, thereby taking into consideration variations of head size.

TMS coil placement according to the 10-20 system was used e.g. to supposedly reach the dorsolateral prefrontal cortex (DLPFC) by placing the coil above F3 and F4 (Gerloff et al. 1997; Rossi et al. 2001), or to target the posterior parietal cortex by placing the coil above P3 and P4 (Kessels et al. 2000; Muri et al. 2002). Hoffman et al. (2000) stimulated between T3 and P3 (TP3) in order to treat auditory hallucinations. The 10-20 system is easily applicable in its practical use, and from an economical perspective at low costs compared to neuroimaging based methods. However, the evidence for ascribing the 10-20 positions to certain anatomical locations is small. Few studies with small numbers of subjects reported corresponding anatomical sites to some electrode positions using imaging techniques (Homan et al. 1987; Steinmetz et al. 1989; Towle et al. 1993). Therefore, we attempted to add to this evidence by investigating stereotactically the underlying anatomy of mainly used 10-20 positions in TMS studies, in order to provide information for TMS coil placement.

Methods

Twenty-one subjects (age 23-62, 10 female, 11 male) were included in this study being a part of other studies ap-

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proved by the local ethics committee, for which they gave written informed consent. For each subject a structural T1-weighted high resolution MRI (isotropic voxels 1×1×1 mm) was acquired in a 1,5 T Magnetom Vision or Synfonie MR Scanner (Siemens, Germany) for later neuronavigation.

The subjects were seated in a comfortable chair. Commercial standard extended 10-20 EEG stretch caps for 39 channels designed according to the 10-20 system (Falk Minow Services, Germany; documentation on: www.easycap.de) were used to define the 10-20 positions. The EEG caps considered the relative distances of 10%, or 20% respectively, of the individual distances from the vertex to the relevant landmarks by requiring exact adaptation of the cap to these landmarks and by its stretching character. The cap sizes were selected according to the individual head size and fitted to the subjects' heads by a trained EEG technologist and an assistant (SG, PS).

A neuronavigational system (Surgical Tool Navigator, STN, Zeiss Oberkochen), based on frameless stereotaxy, was adapted to navigate a magnetic coil to the individually determined anatomy (described in Herwig et al. 2001b). It served to register the position of the magnetic coil, or in this study of the reference pointer representing the midpoint of the coil, relative to a dynamic reference frame mounted on the EEG cap on the subjects' head. The position of the pointer in space and the head position were referenced to the structural MRI and visualized in the three spatial dimensions x, y and z.

We targeted the pointer to the 10-20 positions F3, F4, T3, TP3, P3 as these positions were the most often used in TMS studies. The pointer tip was held perpendicular to these sites and visualized on the computer screen. The visualized tip of the pointer was virtually prolonged by 15 mm so that the underlying cortex, and therefore the region that in case would be stimulated, was reached. An archive image of the anatomical site was saved showing the horizontal, sagital and coronal planes (figure 1). This cortical site was then identified in the Talairach atlas (Talairach and Tournoux 1988), and the corresponding anatomical description, its Brodmann area (BA) and the coordinates were derived. We referred to the macro-anatomical structures, instead for instance using an automated approach with mathematical transformation of the navigator coordinates into Talairach space and then identifying the resulting anatomical sites, because we were thus able to consider the individual anatomy. In some cases the attribution of BAs to a certain coordinate was inconsistent in the Talairach atlas comparing all planes. In these cases that BA was selected which was identified in two of the three planes. The Talairach coordinates were visualized as dots in a surface rendered individual MRI of which the brain size was transformed, and thereby normalized, to the Talairach brain size using the BrainVoyager software (BrainInnovation) (figure 2).

Results

The cortical regions underlying electrode positions F3 and F4 corresponded to parts of Brodmann areas (BA) 8 and 9 within the dorsolateral prefrontal cortex on the medial frontal gyrus. In two subjects F3 was found to be dorsally above the border of BA 6 to 8 (the same was found for F4 in one subject). The mean coordinate for F3 was -37/27/44 within the left DLPFC, corresponding to the dorsal and superior edge of BA 9, bordering BA 8 (mean data and the BAs reached in table 1). The anatomical centre of the DLPFC, however, is more anterior and inferior.

The regions beneath T3 were BAs 22 and 42, being mostly on the superior temporal gyrus and to a less extent on the middle temporal gyrus. BAs 21 and 40 were reached in one subject each. When targeting TP3, the dorsal edge of the principal sulcus, mainly the supramarginal gyrus and as well the angular gyrus (corresponding to BAs 40 and 39), were reached, as well as BA 22 in two subjects.

Targeting P3 reached mainly BA 40 and lesser BA 7 on the inferior and posterior parietal lobe in the region of the intraparietal sulcus, and further in two subjects BA 39.

Hence, in about 10% of the measurements, areas adjacent and possibly functionally distinct compared to the main areas were reached (table I, figure 2). The interindividual variations in the different axes concerning one electrode position were below the range of two centimetres (except for TP3 with a y-axis range of 23 mm). The maximum ranges in the x-, y-, and z-axes were 16, 23, and 18 mm.

Discussion

The results point out that the electrode positions F3, F4, T3, TP3, and P3 of the 10-20 system can be used for coil positioning with an interindividual range of mainly less than two centimetres in the three spatial dimensions. The corresponding cortical area of F3 and F4 was the DLPFC, of T3 the superior temporal gyrus, and of P3 the region of the intraparietal sulcus. In about 90% of the subjects the placement was within these distinct cortical regions or within up to two adjacent Brodmann areas. However, different BAs may be reached in different subjects when targeting the same electrode position, assuming to possibly reach areas with different neuropsychological functions. This puts, for finer grained targeting, the reliability of the method into perspective. Thereby, the size of the stimulated area should be considered which may be even by focal TMS up to several square centimetres dependent on the intensity (Roth et al. 1990; Herwig et al. 2002). In future, TMS positioning may be improved by orientation according to new brain atlases like the four dimensional probabilistic atlas of the

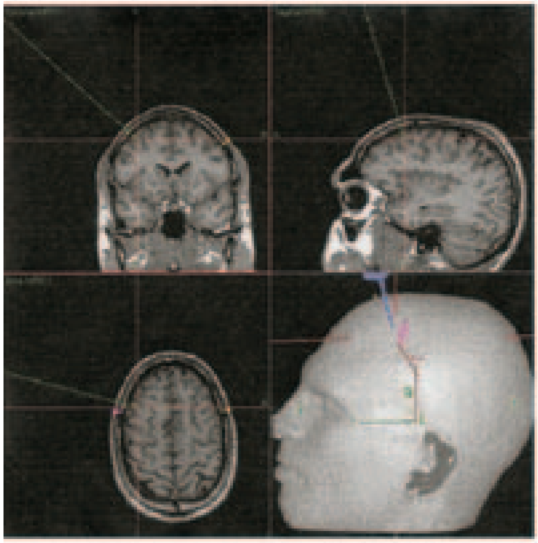

Fig. 1

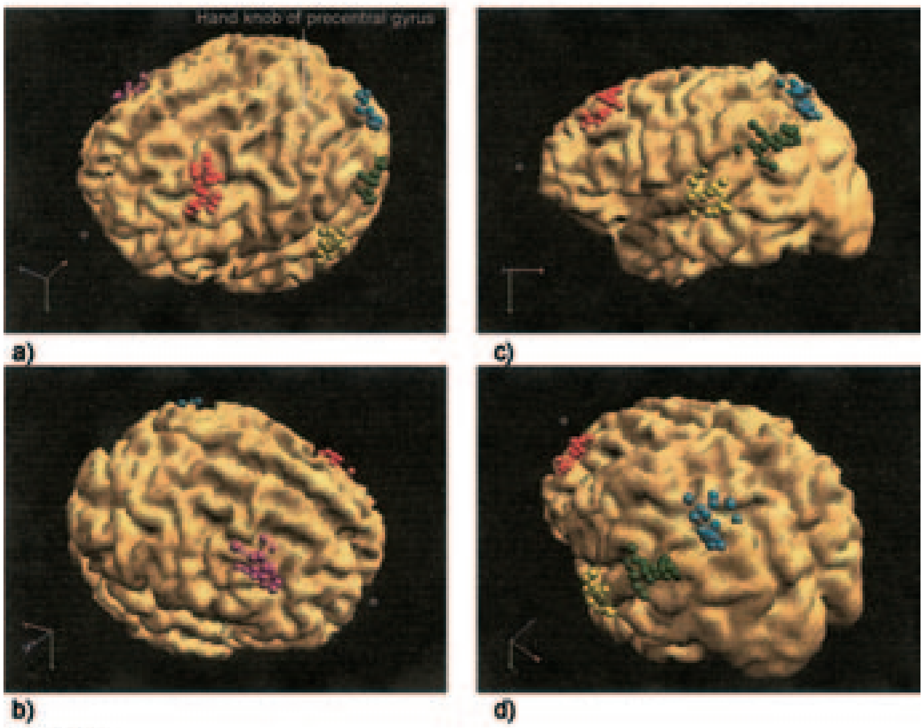

Fig. 2a-d

Figure 1. Real time visualization during the measurements of the 3 MRI axes and a 3D-surface rendered MRI of the head. The dotted green line represents a perpendicular elongation of the pointer by 15 mm. The pointer corresponds to the midpoint of the magnetic coil. It is targeted to F3 in this case. This anatomical site was then identified in the Talairach atlas. A = anterior, P = posterior, R = right, L = left, H = head, F = feet. Upper left: axial plane, upper right: sagital plane, lower left: horizontal plane, lower right: surface rendered 3-D image of the head.

Figure 2 a-d. Visualization of the different 10-20 electrode positions on a Talairach-size-transformed (normalized) and surface-rendered MRI of a subjects' brain. The dots indicate the individual electrode positions of all 21 subjects relative to the cortex. The red dots indicate F3, violet F4, yellow T3, green TP3, blue P3. Few dots are hidden behind others or are just below the brain surface and are therefore not visible within the clusters. The different perspectives are chosen to provide best view onto the intended area. The coordinate crosses reflect the orientation, with the green x-axis pointing rightwards, the red y-axis backwards, and the blue z-axis downwards. Additionally, the asterisks indicate the direction to which the frontal poles point. a) F3 was mainly above the left DLPFC and corresponding to BA8/9, b) F4 was the same on the right hemisphere, c) T3 was mainly above the superior temporal gyrus, and TP3 above the supramarginal and angular gyrus, d) P3 was in the region of the intraparietal sulcus.

Table I. Mean data for the 10-20 positions F3, F4, T3, TP3, P3, presenting the Talairach coordinates (x, y, z) and Brodmann Areas (BA). The mean coordinate and the range (in mm) of the coordinates of the 21 subjects is given, as well as the amount of measurements above the different Brodmann Areas.

	F3			F4			T3			TP3			P3		
	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
mean	-37	27	44	39	26	43	-59	-22	6	-57	-49	28	-38	-62	47
range	13	16	17	12	18	15	7	15	17	12	23	18	16	13	15
	BA 9 n=5			BA 9 n=4			BA 21 n=1			BA 22 n=2			BA 7 n=5		
BA n=	8/9 n=6			9/8 n=7			21/22 n=5			39 n=4			40 n=10		
	8 n=8			8 n=9			22 n=4			39/40 n=5			40/7 n=4		
	6/8 n=2			6/8 n=1			22/42 n=3			40 n=11			39 n=2		
				42 n=7											
				40 n=1											

human brain (Mazziotta et al. 2001), with modern approaches to integrate MRI anatomy, cytoarchitecture and functional neuroanatomy.

Despite its meaning in clinical use and research, particularly in the field of EEG, the anatomical correlations of the 10-20 system have rarely been investigated. The corresponding newer studies, using computer tomography (Homan et al. 1987), MRI (Steinmetz et al. 1989; Lagerlund et al. 1993), and stereotaxic approaches in few subjects (Barnett et al. 1993; Towle et al. 1993) presented results that are largely confirmed by our study. However, certain differences should be mentioned. Homan et al. (1987) attributed the area of F3 and F4 in 12 subjects to the middle frontal gyrus stating this region to be mainly BA 46 and 9, whereby we found these positions to be above BA 8 and 9. Towle et al. (1993) used stereotaxic digitizing (Polhemus Corp.) in four subjects and ascribed T3 and T4 mainly to the middle temporal gyrus. These differences may be explained by different methodological approaches. Our stereotaxy enabled the precise identification of cortical areas being in closest distance beneath the electrode, avoiding errors resulting from the projection of supra-skull markers or digitized landmarks onto the cortex. Further, unlike others, we used the established Talairach atlas to identify Brodmann areas. In our study, the 10-20 positions were identified by using fitted head size adapted commercial caps. Using these EEG caps is common in clinical and scientific routine reflecting every-day practice, and was reported in several peer reviewed EEG studies (e.g., Haan et al. 2000; Kiefer 2002; Ruchsow et al. 2002). The application of caps serves as standardized reference for positioning and is less susceptible to individual measurement errors or inter-investigator differences. One may argue that the use of EEG caps may lead to different results compared to manual measurement of the electrode positions. In order to approach this issue, we performed additional conventional manual measurements of the 10-20 positions F3, F4, T3, P3 in three subjects and found both methods to be essentially congruent. Regarding a precise matching in the x-, and y-dimensions, the amount of hairs may be to consider for possible variations of millimetre range in the z-dimension.

Compared to the 10-20 method, other not-neuroimaging based TMS positioning strategies as are the orientation according to anatomical landmarks like the vertex, or according to functional criteria like a motor response, are limited because they provide much less different points for the orientation. Neuroimaging or stereotaxic approaches are expensive, whereby stereotaxy provides best accuracy (overview in Herwig et al. 2001b).

Many working groups performing TMS studies may not have easy and/or daily access to neuroimaging based methods or to stereotaxic positioning methods, or they may need only a medium grade of precision for their study purpose. Then it may be advantageous to orient the coil according to the 10-20 method.

In most TMS studies to treat depression, the "5-cm-rule" has been applied. However, this strategy may not target the DLPFC reliably (Herwig et al. 2001a). The 10-20 system may provide a better approach. In order to target e.g. the left DLPFC, or BAs 9 and 46, respectively, an extrapolation of our data would support to guide the coil by measuring from F3 (F4 right-sided) one cm in an antero-lateral direction (for orientation see figure 2), or alternatively to target the midpoint of the triangle between F3, F7 and Fp1.

In conclusion, the 10-20 system provides reliable coil positioning within larger scale cortex areas without needing neuroimaging procedures. It appears to be an acceptable compromise between individuality and precision on the one hand and costs on the other. However, if high precision is desired, neuroimaging based or stereotaxic placement of the coil may be recommended.

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