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The five percent electrode system for high-resolution EEG and ERP measurements

Robert Oostenveld[a,b,*], Peter Praamstra[c]

[a]Department of Clinical Neurophysiology, Institute of Neurology, University Hospital Nijmegen, P.O. Box 9101, NL-6500 HB Nijmegen, The Netherlands
[b]Department of Medical and Biophysics, University of Nijmegen, Nijmegen, The Netherlands
[c]Behavioural Brain Sciences Centre, University of Birmingham, Birmingham, UK

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Abstract

Objective: A system for electrode placement is described. It is designed for studies on topography and source analysis of spontaneous and evoked EEG activity.

Method: The proposed system is based on the extended International 10–20 system which contains 74 electrodes, and extends this system up to 345 electrode locations.

Results: The positioning and nomenclature of the electrode system is described, and a subset of locations is proposed as especially useful for modern EEG/ERP systems, often having 128 channels available.

Conclusion: Similar to the extension of the 10–20 system to the 10–10 system ('10% system'), proposed in 1985, the goal of this new extension to a 10–5 system is to further promote standardization in high-resolution EEG studies. © 2001 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Electrode placement; High resolution EEG; High resolution ERP; Nomenclature

1. Introduction

As early as the first International EEG congress, held in London in 1947, it was recognized that a standard method of placement of electrodes used in electroencephalography (EEG) was needed. Possible methods to standardize electrode placement were studied by H.H. Jasper, which resulted in the definition of the 10–20 electrode system (Jasper, 1958). Since then, the 10–20 electrode system has become the de facto standard for clinical EEG. It has also proven to be very useful in the study of event-related potentials (ERPs) in non-clinical settings. However, the advancement of topographic methods to study spontaneous and evoked potentials, and the advancement of multi-channel EEG hardware systems necessitated the standardization of a larger number of channels. Therefore, in 1985 an extension to the original 10–20 system was proposed which involved an increase of the number of electrodes from 21 up to 74 (Chatrian et al., 1985). This extended 10–20 system of electrode placement, also known as the '10% system' and referred to as 10–10 system hereafter, has been accepted and is currently endorsed as the standard of the American Electroencephalographic Society (Klem et al., 1999; American Electroencephalographic Society, 1994) and the International Federation of Societies for Electroencephalography and Clinical Neurophysiology (Nuwer et al., 1998).

Laboratories pursuing EEG and ERP studies of brain activity nowadays have the possibility of using a greater number of channels than the original 21. Measuring ERPs with 64 channels has become quite common. This number of channels can be accommodated within the 74 locations in the 10–10 system. Manufacturers of EEG supplies have recognized this, and electrode caps which enable easy placement of the electrodes according to the 10–10 standard are available. Currently, more and more researchers are moving to an even higher number of channels, and EEG acquisition systems with 128 channels are not uncommon any more. Even 256 channel EEG systems are commercially available now (Pflieger and Sands, 1996; Suarez et al., 2000).

Although measurements of high-resolution EEG and ERP scalp distributions with 128 channel systems are being carried out already, there is at present no standard for the placement of this number of electrodes. For the purpose of mapping the potential distribution, or performing source analysis on this distribution, the individual electrode system

* Corresponding author. Tel.: +31-24-3613973; fax: +31-24-3615097.
E-mail address: roberto@mbfys.kun.nl (R. Oostenveld).

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of a laboratory and even any electrode placement on an individual subject is suitable as long as the positions are known accurately, e.g. by measuring them using a 3D tracker. However, to compare the EEG recordings on individual channels between laboratories for meta-analysis and to enable comparison with older studies using a smaller number of electrodes, standardized electrode locations are needed. This need is recognized by many laboratories, and in measurements with 128 EEG channels or more, a subset of these electrodes usually will correspond to the standard 10–20 system. In fact, a recommendation to identify within dense electrode arrays a number of landmark electrodes that correspond to standard sites within the 10–20 system was recently formulated in the Guidelines for human event-related potentials studies by the Society for Psychophysiological Research (Picton et al., 2000). Nevertheless, reporting on, and comparing EEG from channels other than the standard 74 channels of the 10–10 system is not easily possible. Standardization of the location of additional measurement sites would therefore be an improvement.

Currently, projects are being pursued by the International Consortium for Brain Mapping (ICBM) and in the context of the European Computerized Human Brain Database (ECHBM) to create tools and databases for the neuroscientific community to share the results of functional and anatomical neuroimaging research. These projects rely on the exchange of well-defined neuroimaging data, which for the case of EEG would be improved by further standardization of the increasing numbers of recording sites.

To our knowledge, no standard system suitable for describing the locations of scalp potential measurements at 128 or more locations is currently available. In this paper, we would like to propose such a system. The electrode system which we describe contains the standard locations of the original 10–20 system and those of the 10–10 system. Our proposal is a logical extension of the 10–10 system, enabling the use of up to 345 electrode locations. As the system uses proportional distances of 5% of the total length along contours between skull landmarks, compared to the 20 and 10% distances used in the 10–20 and 10–10 systems, respectively, we call it the 5% system or the 10–5 system.

2. Description of electrode locations

First we will briefly review the method to determine the electrode locations of the 10–10 system. This description of the 10–10 system suits as a reference to the original standard and it clarifies the step from the 10–10 system to the 10–5 system. Based on the locations of the 10–10 system, we explain the extension to the 5% system, and we propose a nomenclature for the additional locations.

2.1. The 10–10 system

The placement of electrodes is based on landmarks on the skull, namely the nasion (Nz), the inion (Iz), and the left and right pre-auricular points (LPA and RPA). The first step is to form the line from Nz to Iz, approximately over the vertex. To determine the location of the vertex, the contour from LPA to RPA is also passed over the vertex. These two contours should intersect at 50% of their lengths and the point thus obtained is the exact vertex.

Along the sagittal Nz-Iz scalp contour over the vertex, the positions Fpz, AFz, Fz, FCz, Cz, CPz, Pz, POz and Oz are marked at 10% distances along this antero-posterior contour (Fig. 1). With position Cz at 50% along this contour, corresponding to the vertex, the position of Oz is at a distance of 90% from Nz and 10% from Iz.

Along the coronal LPA-RPA scalp contour over the vertex, the positions at 10% above the LPA and the RPA are marked. These positions are necessary to determine the horizontal contours over the left and right temporal lobe.

A horizontal circumferential contour is determined over the left temporal lobe from Fpz to Oz, through the location which was marked at 10% above LPA. Along this contour, the positions Fp1, AF7, F7, FT7, T7, TP7, P7, PO7 and O1 are marked at 10% distances (Fig. 1, innermost circle). The circumferential contour over the right temporal lobe is determined in the same fashion from Fpz to Oz over the location 10% above RPA, and the positions Fp2, AF8, F8, FT8, T8, TP8, P8, PO8 and O2 are marked at 10% distances.

A coronal contour is determined from left to right from location T7 to T8, through location Cz. Along this contour at fractions of 1/8 from the total distance, the positions C5, C3, C1, Cz, C2, C4 and C6 are marked. This is conveniently done by bisecting the contour twice on each hemisphere, dividing it in halves and quarters. Similar coronal contours are determined along FT7-FCz-FT8, T7-Cz-T8, TP7-CPz-TP8, P7-Pz-P8 and positions at fractions of 1/8 along these contours are similarly marked. The labels to these locations are described in Fig. 1.

A further coronal contour is determined from left to right over the anterior part of the head, going from location AF7 to AF8 and through location AFz. The distance along this contour for each hemisphere is bisected, giving location AF3 and AF4. Following this, the bisection is repeated, and the additional positions are marked. This gives along this contour, at fractions of 1/8 of the total distance, the locations AF5, AF3, AF1, AFz, AF2, AF4 and AF6. The same procedure is performed for the coronal contour from PO7 to PO8 through POz, giving the locations with labels as shown in Fig. 1. Although, the positions AF1, AF2, AF5, AF6, PO1, PO5, PO2 and PO6 are not explicitly mentioned and displayed in the standard 10–10 system (Klem et al., 1999), they were already present implicitly.

2.2. The extension to the 5% electrode system

The nomenclature to extend the number of coronal contours in the original 10–20 system, labelled F, C and P, utilizes the combination of two letters to indicate the contours lying halfway between these original contours.

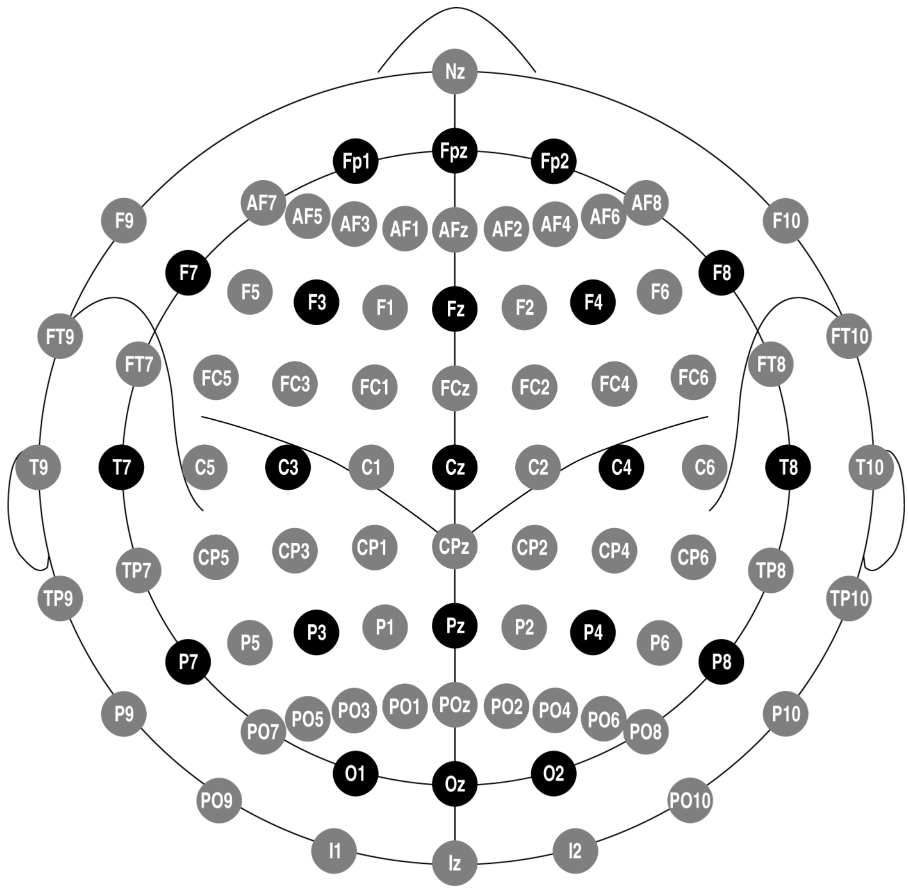

Fig. 1. Electrode positions and labels in the 10–20 system. Black circles indicate positions of the original 10–20 system, gray circles indicate additional positions introduced in the 10–10 extension.

This resulted in the contours FC and CP. The electrodes between the P-contour and the occipital (O) electrodes were likewise labelled with PO, the electrodes between the F-contour and the frontal pole (Fp) electrodes were labeled AF (antero-frontal).

This idea is similar to the naming of geographical directions, derived from the orientations of a compass. For example, halfway between North and West (at 315°) lies the direction North-West. The direction halfway North and North-West (at 337.5°) is commonly labelled North-North-West. We would like to propose the same method for labelling the intermediate positions on the head in the antero-posterior direction. In this way, the locations on the contour between the C-contour and the CP-contour for example get labelled 'CCP'. This naming scheme for the coronal contours gives from anterior to posterior locations the following names: AF, AFF, F, FFC, FC, FCC, C, CCP, CP, CPP, P, PPO, PO. The contour halfway between Fp (frontal pole) locations and the AF contour would be called AFp (which we prefer over FpA). Likewise, the contour between the O locations and the PO contour would be called POO.

To keep a regular and approximately equidistant electrode spacing in each direction, it is also necessary to extend the number of locations along the medial-lateral direction. In the original description of the 10–20 system, this was accounted for by defining electrode positions like Fz-F3-F7, leaving room for electrodes F1 and F5 in between. This enabled a smooth extension of the 21 electrodes in the original 10–20 system towards the 74 electrodes defined in the 10–10 system. We would like to propose an extension of the nomenclature to double the number of locations assigned to a medial-lateral scalp contour. Our proposal is to name new electrode locations lying halfway between two existing electrodes with the name of the most lateral electrode, appended with the letter 'h' (stands for 'half'). For example, the location in between Cz and C1 would be labelled 'C1h.' Similar to the 'z' in Cz which means 'zero,' the 'h' stands for 'half' according to this convention. The electrode name C1h should be read as 'halfway electrode C1.' Indicating the half with $^1/_2$ would also be possible, but we find this less convenient due to the absence of the character $^1/_2$ on the keyboard and in the ASCII character set of computers. The $^1/_2$ is present in the ISO 8859 extensions to the ASCII character set, but these are language specific, which could lead to problems in the internationalization of this nomenclature.

The doubling of electrode positions along the medial-lateral direction should not only be defined for the existing contours in the 10–10 system, but also for the newly defined medial-lateral contours. To give an example: the electrode location between C3 and C5 would be called C5h, the location between CP3 and CP5 would be CP5h. The location halfway between C3h and CP3h would be called CCP3h.

This system for electrode placement and the associated naming scheme give rise to a doubling of the number of medial-lateral electrode contours, and to a doubling of the number of electrodes along these contours. Therefore, the total number of electrode locations available in the 5% electrode system is approximately 4 times the number available in the 10–10 system. The total number of locations in this system is around 345, depending on how many electrodes on the most inferior rows ('9' and '10') are included. Fig. 2 shows the locations of the electrode sites defined according to this system. Black filled circles indicate the electrode locations of the 10–20 system. Electrode sites of the 10–10 system are indicated by grey filled circles. Intermediate electrode sites defined by the 5% system are marked as dots. In this figure, a selection of the 5% electrode locations is indicated by open circles including their electrode names. This selection of electrodes, combined with the 10–10 system, leads to a subset of 142 electrodes with a complete and homogenous coverage of the head; see Figs. 3–5. The combination of the positions of the 10–10 system with these additional 5% positions would provide a good starting point for 128 channel EEG measurements, where possibly some of the lowest electrodes can be skipped.

Due to the nature of the definition of the 10–20 system, the electrode rows at the most occipital and frontal part of the head (PO en AF) become very crowded. Probably for this reason, the representation of the 10–10 system in the AES Guideline (American Electroencephalographic Society, 1994) places only one electrode between POz and PO7 (similar for POz-PO8 and the AF row). Placing three electrodes between POz and PO7 is hardly feasible in practice. The pragmatic solution is that two electrodes are placed in between POz and PO7. In that case, the optimal distribution of the electrodes (with distances of 33% between electrodes) does not match with the available labels for the three locations which are defined at 25% positions along that row (PO1, PO3 and PO5). Naming these two electrodes according to two of the three available labels for that row in the 10–20 system is clearly not appropriate. We therefore label these electrodes according to the locations in the 5% system

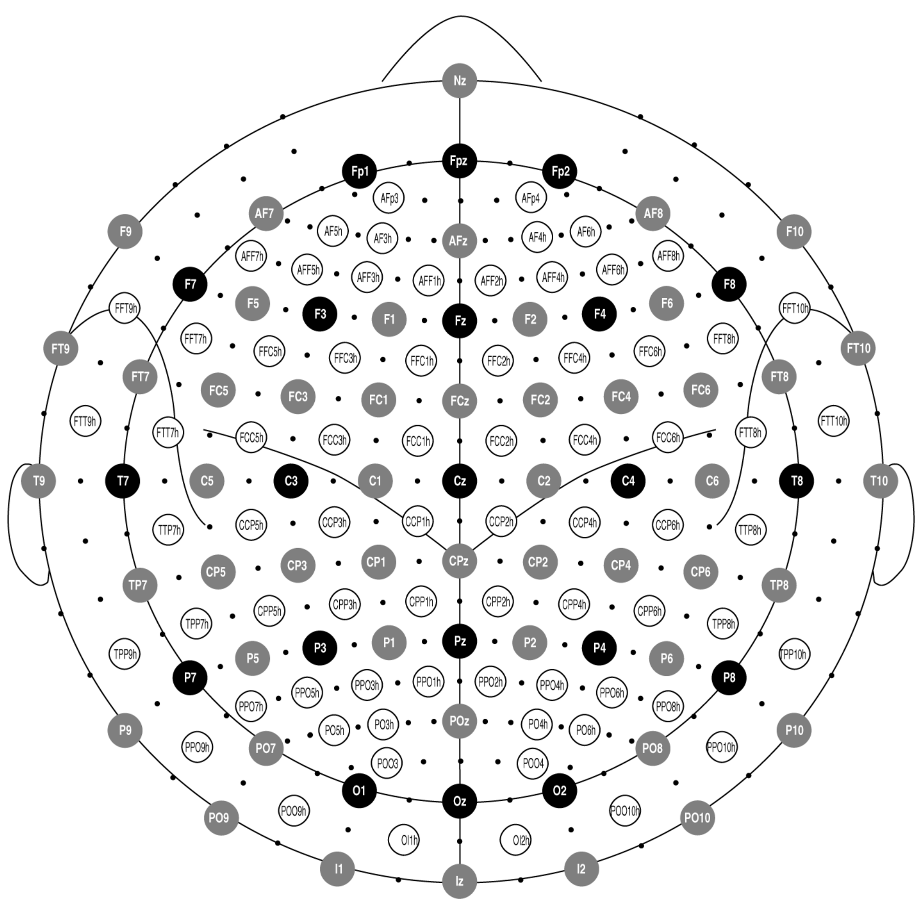

Fig. 2. Electrode positions in the proposed 10–5 system. Positions additional to the 10–10 system are indicated with dots; a selection of additional positions useful for a 128 channel EEG system are indicated with open circles.

as close as possible to their actual locations (PO3h, PO5h, AF3h and AF5h); see Fig. 2.

2.3. Notes on extended electrode nomenclature

In the proposed system for electrode placement, the assignment of unique identifying labels to each location is as important as the location of the additional electrodes. In the past, when it became apparent that the original 10–20 system with 19 electrodes did not offer enough electrode locations, different proposals were made for this nomenclature (reviewed in Nuwer, 1987). These included adding single and double primes to the electrode name, introducing the additional letters B, D, E and H to designate intermediate coronal rows, and appending a letter a (for anterior) and p (for posterior) to the beginning or end of the electrode label.

The nomenclature that eventually became the standard, uses combinations of letters used in the original 10–20 system, and gives the electrode row in between, for instance, the electrodes P and O the name PO. This has as main advantage that electrode labels are still linked to underlying cortical structures. The nomenclature we propose here for the additional electrodes follows the same logic. Readers familiar with the original and the extended 10–20 system will appreciate the simplicity of this naming scheme, and will have little problem locating the electrode site on the head given one of the labels of an intermediate electrode.

According to the 10–20 standard (American Electroencephalographic Society, 1994), the locations 10% below electrodes O1 and O2 are called O9 and O10 as these electrodes lie on the horizontal lines '9' and '10.'

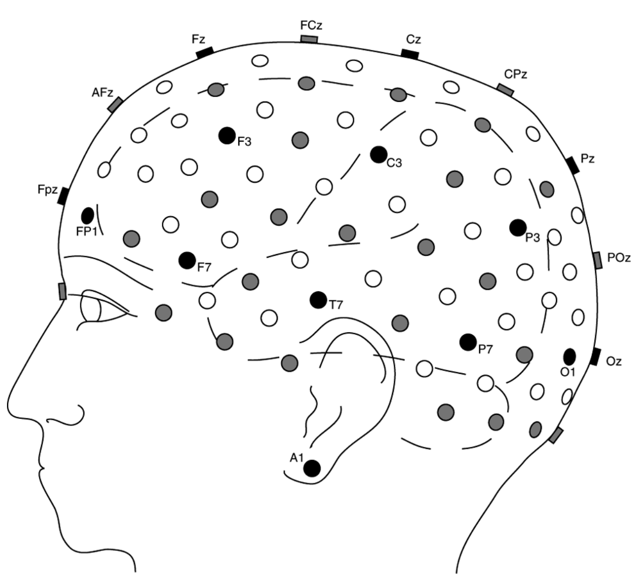

Fig. 3. Selection of 10–5 electrode positions in a realistic display, lateral view. Additional electrode labels can be found in Fig. 2. The head and brain contours are modelled after Chatrian et al. (1988).

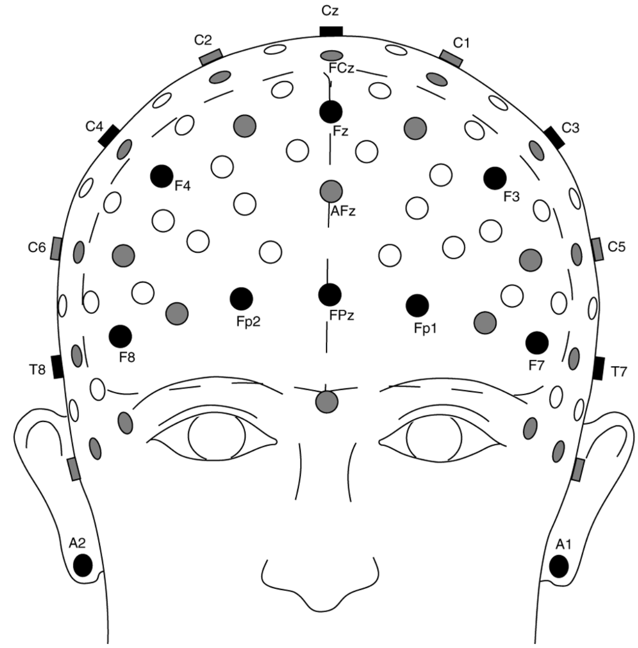

Fig. 4. Selection of 10–5 electrode positions in a realistic display, anterior view. See Fig. 3 for further information.

However, the placement of the occipital electrodes O1 and O2 (as well as Fp1 and Fp2) does not follow the general rule of being distributed along a coronal contour, which becomes apparent when asking where hypothetical electrodes O3, O5 and O7 should be located. For this reason, we prefer to label the electrode locations next to the inion in the same manner as those next to Oz, and we suggest to use the labels I1 and I2. This also facilitates the extended 5% nomenclature for the intermediate 5% positions below the occipital (O1, Oz and O2) electrodes: halfway O1 and I1 lies OI1, whereas otherwise the name would have to indicate a location halfway between O1 and O9 (perhaps O5 or O9h). Alternatively, the nomenclature of (cerebellar) Cbz, Cb1 and Cb2 would be a viable alternative to Iz, I1 and I2 (comparable to, but slightly different from Chatrian et al. (1985, 1988)).

2.4. Pitfalls for mislocalization

The determination of electrode sites strongly depends on the anatomical markerpoints. One starts with determining the contours nasion-inion and LPA-RPA. These should intersect each other at 50% of their respective length, which leads to an unambiguous localization of the vertex point (Cz). The next step is then to determine the line from the point 10% above nasion (Fpz) to the point at 10% above LPA. Since the line between any two points on a surface is ambiguous, the determination of the bottom ('7') electrode row should be done using a plane which passes through the points located 10% above nasion, LPA and inion (likewise for the right hemisphere). The intersection of this plane with

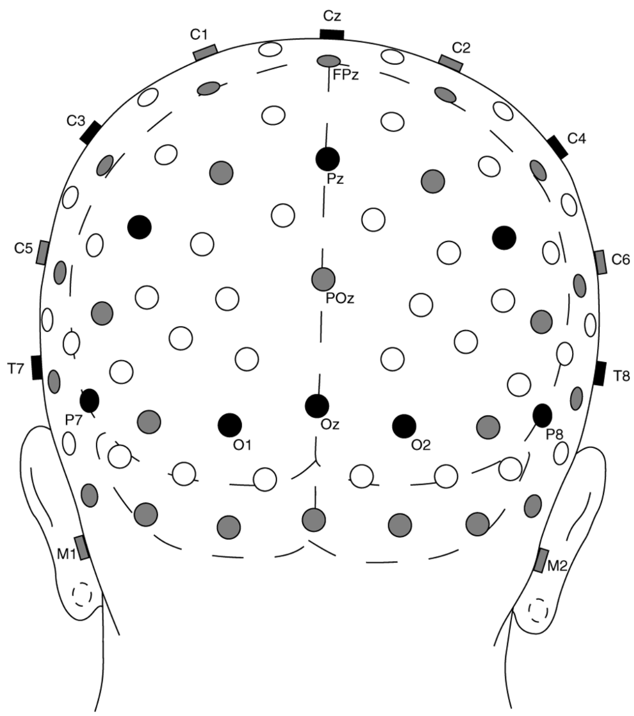

Fig. 5. Selection of 10–5 electrode positions in a realistic display, posterior view. See Fig. 3 for further information.

the head surface gives the surface contour along which the left bottom ('7') electrodes are distributed. Likewise, the right bottom ('8') electrodes are distributed along the intersection of the plane through the locations 10% above nasion, RPA and inion with the head surface.

The description using the intersection of these planes with the head surface has been described by Le et al. (1998) in the design of an algorithm for fast electrode placement. Their description is slightly inaccurate in that it uses an anterior plane through the points 10% above nasion, LPA and RPA, and a posterior plane through the points 10% above LPA, RPA and inion (see their Fig. 1). These planes intersect at the line passing through the points 10% above LPA and RPA. However, the description of the standard 10–20 system describes that 'a circumferential measurement is taken over the temporal lobes, from midline Fp (Fpz) to midline O (Oz)'. This would be implemented using the intersection of a plane through Fpz, the point 10% above LPA and Oz with the head surface. The result would be that the two planes would go through the left and right hemisphere, respectively, instead of through the anterior and posterior part of the head. In the description by Le et al. (1998), the electrodes FT7 and TP7 do not necessarily lie on a line, whereas in what we believe to be the correct description (which is especially important when implementing this in a computer program) FT7 and TP7 would, but Fp1 and Fp2 would not.

To prevent another pitfall, it should be stressed that electrode locations T7 and T8 do not necessarily lie on the line over the vertex connecting LPA and RPA. This coronal line should only be used to determine the height (10% above left and right PA) of the temporal electrode sites. The actual location of T7 and T8 should be halfway between Fpz and Oz, along the horizontal line over the temporal lobe, as described above.

In the AES Guideline (American Electroencephalographic Society, 1994) the inferior electrodes PO9 and O9 are placed 10% below electrodes PO7 and O1. This description is not sufficiently accurate for an unambiguous localization, since it only describes the height, and not the location along the horizontal direction. Alternatively, Chatrian et al. (1985) places inferior electrodes Cb1′, Cb1 (in their nomenclature) 10% below the '7' row unambiguously along the coronal lines through P7, PO7 and places Cb1″ along the line connecting PO3 and O1.

The schematic drawing in the Guideline (American Electroencephalographic Society, 1994, their Fig. 1) suggests that the inferior electrode locations lie on a line connecting all these electrodes and passing through Nz and Iz. This would imply that the electrodes in the inferior ('9') row lie on the same height, at equal distances along a horizontal contour lying 10% below the '7' row. This is compatible with the textual description of these locations, and it is based on the concept of distributing them along a horizontal contour. The description for localizing inferior electrodes in Chatrian et al. (1985) is different, since it is based on coronal contours. In practice, these two methods will differ only slightly, but in a computer implementation of an algorithm similar to Le et al. (1998) which could be used in assisting the placement of electrodes, a consistent choice between these two should be made. It is our opinion that the horizontal contour through nasion and inion should be used, since that will result in electrodes which are more regularly spaced.

3. Discussion

The rationale for high-density EEG applications is, ultimately, to facilitate identification of the intracranial sources of scalp-recorded EEG signals. Methods for source characterization thus rely on intermodal matching of EEG data with anatomical information, usually derived from MRI images. In theory, information derived from the scalp-recorded EEG could therefore be projected into anatomical space and communicated through the use of a standardized neuroanatomical atlas, like the Talairach-Tournoux atlas (Talairach and Tournoux, 1988). For the analysis of high-density EEG measurements on individual subjects the most accurate results will be attained if the actual electrode locations are measured, e.g. using a 3D tracker, even when the electrodes were applied according to the 10–5 system. We know, however, that dipole source analyses of human EEG data commonly take averaged data across a number of subjects, rather than the data of one individual, as input (e.g. Opitz et al., 1999). Similarly, reports on high-density EEG studies that do not go beyond a description of the scalp topography still pool data across subjects (e.g. Dehaene et al., 1998; Curran et al., 1993). In practice, therefore, high-density EEG does not obviate the need for reproducible electrode placements guided by internationally accepted conventions.

It has to be emphasized that the 10–5 system unavoidably inherits the limitations of the 10–20 system. Most importantly, individual anatomical differences result in a considerable variability in the localization of brain structures relative to the skull landmarks. As pointed out by Steinmetz et al. (1989), this cranio-cerebral variability is most pronounced for areas remote from the relatively constant central and lateral sylvian structures, especially areas close to the occipital pole. This entails that electrodes placed at the back of the head and electrodes below the Fpz-Oz equator, which are particularly important for source analysis (Scherg and Von Cramon, 1990), are most liable to overlie different brain areas in different subjects. However, this feature inherent to the 10–20 system should not distract from the formulation of unambiguous rules for the placement of these electrodes and the strict adherence to these rules.

The extension of the 10–20 and 10–10 systems to the proposed 10–5 system aims to accommodate the larger number of recording channels available in modern EEG/ERP systems. The proposed extension defines the position and nomenclature of 345 locations of the head, and it can accommodate a homogeneous distribution of a subset containing, for example, 128 electrodes. We believe the extension to be transparent and, more or less in accordance with the practice developed by manufacturers of electrode caps, e.g. Quick-Cap (Quick-Cap Neuromedical Supplies; URL http://www.neuro.com/neuromed/quikcap.htm); Easy-Cap (Falk Minow Services, Germany; URL http://www.easycap.de); ECI Electro-Cap (Electro-Cap International Inc.; URL http://www.electro-cap.com).

4. Comments

A full description of the electrode locations on a spherical head model and of the labels according to the 5% system can be obtained from the first author.

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