Determination of the HydroCel Geodesic Sensor Nets' Average Electrode Positions and Their 10 – 10 International Equivalents

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This technical document describes a study conducted by EGI. The aims of this study are 1) to acquire average electrode positions for the 128- (adult and infant) and 256-channel HydroCel GSN, and 2) to determine the approximate correspondence between the international 10-10 electrode positions with those sensors on the 128- and 256-channel HydroCel GSN.

Method

Subjects

Adults with head sizes fitting the medium (n = 3) and large (n = 2) HydroCel GSNs participated in the study. Five subjects also had 10 – 10 measurements taken for digitization (see below).

Materials

The 128- and 256-channel adult HydroCel GSNs were used to determine the electrode position on the subjects head. The 64- and 128-channel infant GSNs were applied to infant head models obtained from Simuloids Inc. Three infant head models were used: small (35 cm circumference), medium (39.5 cm), and large (43.5 cm). Digitization of the GSN's sensor positions was obtained using the Fastrack digitizer (Polhemus) and the Locator software (Source Signal Imaging).

Procedure

Application of the GSN was done by two trained technicians. This procedure involves identifying the vertex and applying the GSN with reference to this point. Prior to the application of the GSN, Fastrack receivers were placed behind the left and right ear and on the nose. This was accomplished for each subject with the 128- and 256-channel GSN. To obtain positions of the 10-10 electrode system, a registered EEG technician identified the 71 locations (minus the ear positions) on each of the five subjects. A similar procedure was used for the infant model heads.

After application of the HydroCel GSN or determination of the 10-10 positions, each sensor position was digitized using the Fastrack hardware and Locator software. In addition to digitizing the sensor positions the left and right preauricular points, nasion, and inion were also digitized.

Sensor Registration

The objective is to put all such electrode files in a common framework to compare how the electrode montages, on average, sit upon the human head. What follows is a step-by-step sequence for doing this. The choices made are not necessarily unique, but are sensible given the stated objective. Note that the resulting coordinate system is not simply related to any best-fit spheres approximation of the head, as would be used in bioelectric field modeling for example.

1. A Polhemus Fastrak returns the position of each electrode and the fiducial points in some arbitrary coordinate system

$$\vec{r}_i^{(p)} = \left(x_i^{(p)}, y_i^{(p)}, z_i^{(p)}\right)^T$$

where i=1,…,129,L,R,N,V. The first 129 points are the electrode locations. L and R represent the left and right pre-auricular points, N represents the nasion, and V represents the vertex. The vectors to each point each exist in 3-dimensional space in a coordinate independent sense, but the superscript (p) indicates that here these are represented in the Polhemus coordinate system. The superscript T stands for transpose, and reflects our preference toward working with column vectors to facilitate the matrix multiplications below.

2. We conceive a fiducial coordinate system, denoted with a superscript (f), with the following properties. First, its x-axis lies along the line connecting L and R, with the positive direction pointing toward R. Second, its y-axis is perpendicular to the line LR, and passes through the nasion in the positive direction. The x-axis and y-axis intersect at a point, which forms the center of this coordinate system, but with the constraints that: i) the y-axis pass through the nasion, and ii) the x-axis and y-axis meet at a right angle, the intersection will not in general be at the midline of the line LR. As a matter of convention, we are placing more emphasis on the nasion than on the midpoint of the line LR.

3. It is a simple problem in 3-dimensional Euclidean geometry to determine the equation for the unique line passing through the nasion N and intersecting the line LR at a right angle. Let us denote the intersection of these lines with the vector

$$\vec{r}_C^{(p)} = \left(x_C^{(p)}, y_C^{(p)}, z_C^{(p)}\right)^T$$

where the subscript C stands for the center of the fiducial coordinate system in Polhemus coordinates (p). An expression for the location of the point C in a slightly simplified case is given by Strang (1980). In terms of the fiducial position vectors in the Polhemus coordinates, we have

$$\vec{r}_C^{(p)} = \vec{r}_L^{(p)} + \frac{\left(\vec{r}_R^{(p)} - \vec{r}_L^{(p)}\right)\cdot\left(\vec{r}_N^{(p)} - \vec{r}_L^{(p)}\right)}{\left|\vec{r}_R^{(p)} - \vec{r}_L^{(p)}\right|^2}\left(\vec{r}_R^{(p)} - \vec{r}_L^{(p)}\right)$$

4. The next step is to translate all our coordinates to be centered on the above point. This is done trivially with the transformation

$$\vec{r}_i^{(c)} = \vec{r}_i^{(p)} - \vec{r}_C^{(p)}$$

where the superscript (c) denotes that the new vectors are in our so-called "centered" coordinate system. We of course must have the trivial result that

$$\vec{r}_C^{(c)} = (0,0,0)^T$$

that is, the center point C is at the origin of our centered coordinate system (c). We are still not done, however, because this centered coordinate system (c) is rotated arbitrarily relative to our desired fiducial coordinate system (f).

5. We can easily define unit vectors in these centered coordinates, which lie along the axes of the desired fiducial coordinate system. First, the x-axis is defined to lie along the line connecting the center point C and the right pre-auricular point R:

$$\hat{x}^{(c)} = \frac{\vec{r}_R^{(c)}}{\left|\vec{r}_R^{(c)}\right|}$$

(Because the center point C is the origin of our centered coordinate system it does not appear explicitly in the above equation.) Second, the y-axis is defined to lie along the line connecting the center point C and the nasion N:

$$\hat{y}^{(c)} = \frac{\vec{r}_N^{(c)}}{\left|\vec{r}_N^{(c)}\right|}$$

A useful step in verifying the computer implementation is to test that these two vectors are indeed orthogonal. Since they are unit vectors, this may be considered satisfied of their dot product is small compared to unit. Finally, the z-axis is defined to be perpendicular to the resulting xy-plane, with its positive direction determined as usual by the right hand rule:

$$\hat{z}^{(c)} = \hat{x}^{(c)} \times \hat{y}^{(c)}$$

By definition, the fiducial unit vectors have trivial representations in the fiducial coordinate system (f).

$$\hat{x}^{(f)} = (1,0,0)^T$$
$$\hat{y}^{(f)} = (0,1,0)^T$$
$$\hat{z}^{(f)} = (0,0,1)^T$$

6. Our next goal is to determine a matrix which, when applied to the electrode positions in the centered coordinate system (c), will rotate them in to the fiducial coordinate system (f). This is most easily done as follows. We first construct a matrix M, whose columns are the fiducial unit vectors in centered coordinates:

$$\mathrm{M} = \left[\hat{x}^{(c)}\ ,\ \hat{y}^{(c)}\ ,\ \hat{z}^{(c)}\right]$$

This matrix M has the obvious property that, when applied to the fiducial unit vectors in the fiducial coordinate system (f), it translates them into the centered coordinate system (c):

$$\hat{x}^{(c)} = \mathrm{M}\,\hat{x}^{(f)}$$
$$\hat{y}^{(c)} = \mathrm{M}\,\hat{y}^{(f)}$$
$$\hat{z}^{(c)} = \mathrm{M}\,\hat{z}^{(f)}$$

Since any vector in the fiducial coordinate system can be represented as a linear sum of the fiducial unit vectors, the transformation matrix M actually rotates *any* vector from the fiducial coordinate system (f) to the centered coordinate system (c).

$$\vec{r}_i^{\,(c)} = \mathrm{M}\,\vec{r}_i^{\,(f)}$$

Once this matrix is constructed it can be tested by applying it to each of the hat vectors in the (f) basis. It should be that the trivial hat vectors in the fiducial system get transformed to the nontrivial hat vectors in the centered coordinate sytstem.

7. By definition, the inverse of M rotates any vector in the centered coordinates (c) into the fiducial coordinates (f), that is

$$\vec{r}_i^{\,(f)} = \mathrm{M}^{-1}\,\vec{r}_i^{\,(c)}$$

This is our desired result, and can be applied to each of the electrode and fiducial positions. Conveniently, it can be shown that the matrix M is an orthogonal matrix whose inverse is equal to its transpose (Arfken and Weber, 1995).

$$\mathrm{M}^{-1} = \mathrm{M}^T$$

so the inverse of M can be obtained trivially. The final result may be tested by applying the inverse (transpose) matrix to each of the hat vectors in the centered coordinates (c) and verifying that they are properly rotated into the fiducial coordinate axes.

As a final test of the entire set of transformations, one can verify that the distance between each pair of electrodes is preserved. Given the deterministic nature of each of the transformation, this can be expected to be satisfied to within the accuracy of single or double precision. If the distance between each pair of electrodes is preserved, and right pre-auricular point and nasion lie on the fiducial x and y axes respectively, then the coordinate transformation must be correct.

Averaging of Sensor Positions

Once the electrode positions have been co-registered, they were normalized to a unit sphere for all subjects. The positions of the sensor for each GSN and the 10 – 10 were then averaged across the five subjects.

The electrode positions should conform to certain standards if they were placed on an ideal head (i.e., perfectly symmetric). For example, midline electrodes should lie on the midline and all other electrodes should have a homologous site on the opposite hemisphere (the pair should be symmetric). Because real heads are not usually symmetric and because these asymmetries are not completely removed by averaging across the small number of subjects used in the present study, symmetry of electrode positions must be mathematically induced. To obtain symmetry for each version of the HydroCel GSN and the 10-10, the following procedure was used. First, the known midline electrodes were made to lie in the sagital (Y) plane. Second, all electrodes on the left hemisphere were compared to their homologous counterpart by making their X (ear to ear) position positive. The difference between a pair in all three directions was taken and halved. This difference was then used to adjust the position of each of the electrode for that particular pair to make the two electrode positions symmetric.

Determining the 10-10 position equivalence for the HydroCel GSN

Distance between a particular 10-10 position and all sensors for a particular HydroCel GSN (i.e., 128- and 256-channel net) was computed by obtaining the arc length. The three nearest HydroCel GSN sensor positions for that particular 10-10 position were used to determine the approximate 10-10 equivalent in the HydroCel GSN sensor array. The following criteria were used to determine approximate equivalence:

1) Midline 10-10 positions must also be along the midline in the HydroCel GSN array, even if the nearest HydroCel GSN position did not lie on the midline.
2) The nearest HydroCel GSN position was used as an approximate equivalent 10-10 position.
3) No HydroCel GSN sensor equivalence for a 10-10 position could be obtained when the arc distance of all 3 nearest GSN position exceed .20 of the sphere's radius.

Results

Average Positions of the HydroCel GSNs

These are available from EGI by emailing us at support@EGI.com.

The HydroCel GSNs' Approximate 10 – 10 Equivalents

Tables 1, and 2 present the HydroCel GSNs' approximate 10 – 10 equivalents, and Figures 1 and 2 presents approximate 10 – 10 position on the 128- and 256-channel HydroCel GSN.

There are several things to note. First, the 10-20 positions T3/T4 are replaced by T7/T8 and positions T5/T6 are replaced by P7/P8. This is in accordance with the American Electroencephalographic Society guideline. Second, the 10-10 equivalents for 32-, 64-, and 128-channel GSN are the same because they are based on the same geodesic frequency. Third, for the 128-channel configuration P7/P8 is moved to a slightly superior position compared to their locations in the 32-channel net. This is to make room for position P9/P10.

From Table 1, there are several noticeable patterns for the mapping of the 10-20 positions to the 128-channel HCGSN. First, 10-20 positions towards the front of the head (e.g., F3, F4, Fp1, Fp2) have equivalent representations with the HCGSN. These equivalent HCGSN positions are less than 1 cm from the 10-20 positions. Second, caudal and ventral 10-20 positions have less precise representations with the HCGSN, particularly the temporal and occipital positions. Most of the latter 10-20 positions have HCGSN equivalents between 1 and 2 centimeters. Finally, for several 10-20 positions, in particular the temporal positions, the HCGSN contains equivalent sensor positions that are within 2 to 2.5 centimeters.

In contrast to the 128-channel HCGSN, 10-20 positions map quite accurately to the 256-channel HCGSN. Only 5 positions of the 10-20 system are approximated by the HCGSN positions at a distance greater than 1 cm (C3, F8, FP1, FPz, O1); all of these positions have a difference in position less than 1.5 cm.

According to the American Board of Registration of Electroencephalographic and Evoked Potential Technologists (ABRET), when EEG electrodes are applied according to the 10-20 system, the acceptable error bound is 1 centimeter. Thus, 42% of the 10-20 positions have acceptable equivalent positions in the 128-channel HCGSN, and another 42% of the 10-20 positions have 128-channel HCGSN equivalents that are less than 2 centimeters. There are only 16% (3 positions) of the 10-20 positions that have 128-channel HCGSN equivalent positions greater 2 cm (2.1 – 2.5 cm).

Compared to the 128-channel HCGSN, the 256-channel HCGSN maps quite well to the 10-20 system. Of the 19 10-20 positions, 14 (74%) of the positions have equivalent locations, within the ABRET acceptable error bound, on the HCGSN. The increase accuracy of 10-20 mapping to the 256-channel HCGSN reflects the fact that the intersensor distance on the 256-channel HCGSN is much less compared to the 128-HCGSN.

128-Channel HCGSN 58 Centimeters

10 -10	HydroCel	ArcLength (cm)	10 - 10	HydroCel	ArcLength (cm)
C3	36	0.436238892	F2	4	0.635497
C4	104	0.497123711	F5	27	0.796737
Cz	129		F6	123	0.111369
F3	24	0.795011	F9	32	0.634128
F4	124	0.251126	FC1	13	0.90596965
F7	33	2.135136	FC2	112	1.277097778
F8	122	1.510734	FC3	29	0.992441841
FP1	22	0.676512	FC4	111	1.071025231
FP2	9	0.724020	FC5	28	0.946988
FPZ	14	1.719687	FC6	117	1.651589677
FPZ	21	1.812320	Fcz	6	0.839795
FPZ	15	2.153488	Ft10	121	1.677695
Fz	11	0.782608	FT7	34	1.446053
O1	70	1.769700151	FT8	116	1.716114274
O2	83	1.550805764	Ft9	38	1.424932
P3	52	1.700347748	Oz	75	1.044015
P4	92	0.884674687	P1	60	0.420415135
T5-P7	58	1.58875435	P9	64	2.284576896
T6-P8	96	1.152553305	P10	95	1.810215
T3-T7	45	2.445759155	P2	85	1.07775462
T4-T8	108	2.155490778	P5	51	1.424895105
AF3	23	1.360952	P6	97	0.945945361
AF4	3	0.514681	P9	64	2.284577
AF7	26	1.525864	PO3	67	1.234265999
AF8	2	0.879039	PO4	77	1.288728821
Afz	16	0.480872	PO7	65	1.450160316
C1	30	0.69756351	PO8	90	1.773835633
C2	105	0.072678512	Poz	72	0.318779
C5	41	1.059052641	Pz	62	0.741746
C6	103	1.04678466			
CP1	37	1.105318346	T10	114	2.178790
Cp2	87	0.769807058	T11	45	3.291678
CP3	42	0.841452438			
CP4	93	0.499479459	T12	108	3.163653
Cp5	47	0.330299473	T9	44	2.018466
CP6	98	0.497889883	TP10	100	1.223438
CpZ	55	0.337813	Tp7	46	1.140839183
F1	19	1.070047	TP8	102	1.835932481
F10	1	0.949038	TP9	57	1.121168

256-Channel HCGSN 58 Centimeters

10 -10	HydroCel	Distance (cm)	10 -10	HydroCel	Distance (cm)
C3	59	1.029910	AF3	34	0.509761
C4	183	0.623156	C1	44	0.519046
Cz			PO8	161	0.525352
F3	36	0.685314	AF4	12	0.526048
F4	224	0.590697	Afz	20	0.528535
F7	47	0.537374	TP8	179	0.548095
F8	2	1.343284	FC3	42	0.561542
FP1	37	1.053985	CP3	66	0.589000
FP2	18	0.811629	P6	162	0.638474
FPZ	26	1.218066	PO3	109	0.677353
Fz	21	0.845529	C2	185	0.704042
O1	116	1.257897	FC1	24	0.704503
O2	150	0.959035	PO4	140	0.759366
P3	87	0.467009	Oz	126	0.766504
P4	153	0.613058	Cp2	143	0.768954
T3-T7	69	0.565707	FC2	207	0.771819
T4-T8	202	0.347099	CP1	79	0.800214
T5-P7	96	0.766165	TP9	94	0.801732
T6-P8	170	0.394401	F1	29	0.865540
Pz	101	0.126808	Fcz	15	0.916188
Poz	119	0.158625	TP10	190	0.917598
F2	5	0.160534	F10	226	0.922800
FC5	49	0.227681	P2	142	1.012270
Ft10	219	0.242712	F5	48	1.012833
C6	194	0.253742	P9	106	1.048151
Ft9	67	0.259169	FC4	206	1.079352
F6	222	0.298570	Cp5	76	1.084715
FT8	211	0.316283	FC6	213	1.120079
AF8	10	0.321524	Afz	27	1.137608
CpZ	81	0.326043	Po7	97	1.193410
CP6	172	0.344188	AF7	46	1.211161
C5	64	0.354355	Afz	26	1.338032
CP4	164	0.382313	Tp7	84	1.344355
P10	169	0.432754	FT7	62	1.365872
F9	252	0.443114	T9	68	3.302035
P1	88	0.464150	T10	210	3.434444
P5	86	0.500231			

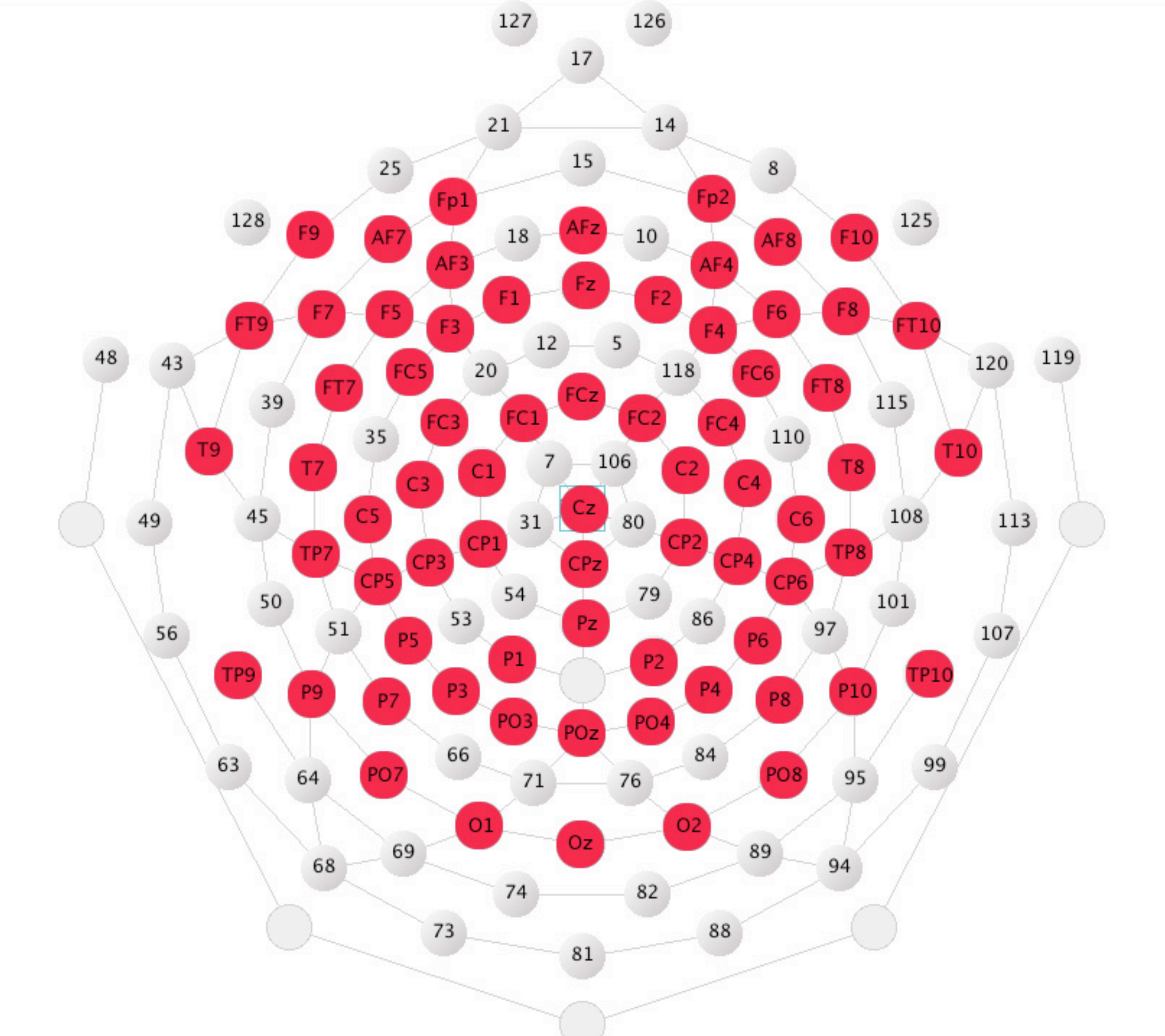
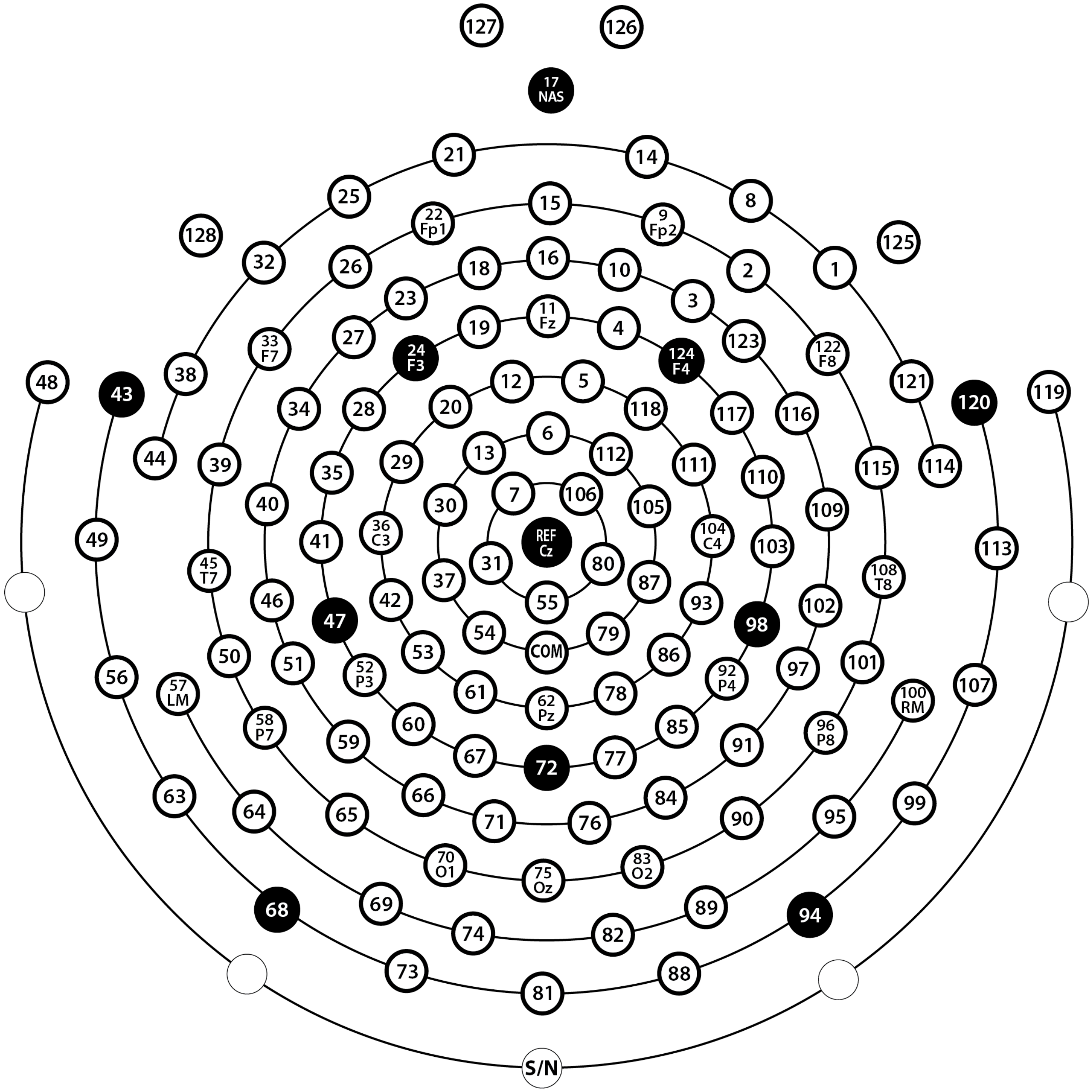


Figure 1. Layout illustrating the approximate 10 – 10 equivalent on the 128-channel HydroCel GSN.


127
126
17 NAS
21
14
25
8
22 Fp1
15
9 Fp2
128
125
32
26
18
16
10
2
1
23
3
27
19
11 Fz
4
123
33 F7
24 F3
124 F4
122 F8
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36 C3
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45 T7
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108 T8
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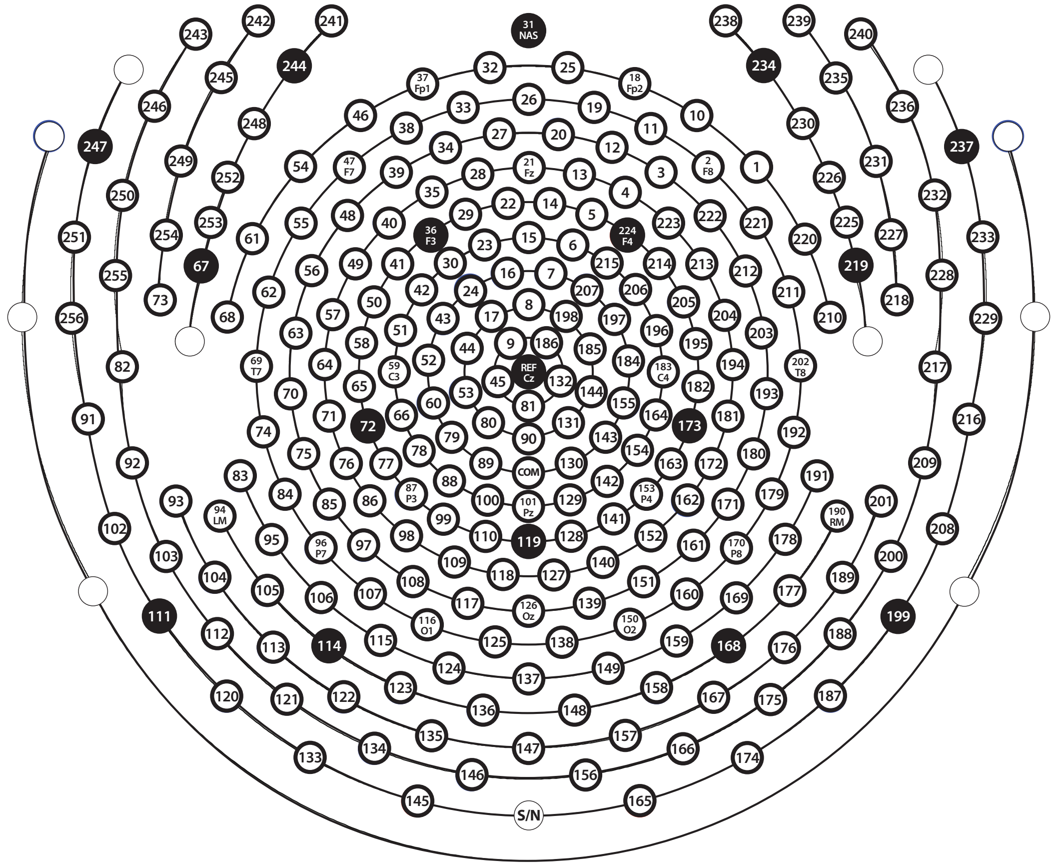
86
97
101
56
57 LM
52 P3
61
COM
92 P4
100 RM
107
58 P7
59
60
62 Pz
78
85
91
96 P8
63
64
65
66
67
72
77
84
90
95
99
71
76
70 O1
75 Oz
83 O2
68
69
74
82
89
94
73
81
88
S/N

Figure 2. Layout illustrating the approximate 10 – 10 equivalent on the 256-channel HydroCel GSN.



References

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