ORIGINAL ARTICLE

Extra-Tympanic Electrocochleography in a Normal Population. A Descriptive Study

Jaume Redondo-Martínez, a,b,∗ Antonio Morant-Ventura, a,b Diana Robledo-Aguayo, c Alejandra Ayas-Montero, c Elvira Mencheta-Benet, c Jaime Marco-Algarra a,b

a Servicio de O.R.L, Hospital Clínico Universitario de Valencia, Valencia, Spain
b Departamento de Cirugía, Universitat de València, Valencia, Spain
c Centro Otoneurológico, Valencia, Spain

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KEYWORDS
Electrocochleography; Extra-tympanic; Diagnosis; Normal; Action potential; Summating potential; Ménière’s disease

Abstract

Introduction and objectives: Extra-tympanic electrocochleography is an electrophysiological register obtained after stimulating the cochlea with an audible stimulus. This stimulus is applied using an earphone over the external auditory canal, while the electrical activity is registered by surface electrodes. There are few studies that analyse normal electrocochleography in our environment. Thus, the main objective of our study was to regularise the values obtained with electrocochleography in ears without any otoneurological diseases. We explain in detail the process of obtaining the register.

Methods: Sixty healthy ears were studied by extratympanic electrocochleography. Statistical results were analysed. While 30 ears were studied with a stimulus at 90 dB, another 30 ears were studied with a stimulus at 80 dB.

Results: Summating potential and action potential latencies and amplitudes were measured. Summating potential/action potential ratios were calculated. Wave I and wave II latencies were also determined. These results were analysed in function of stimulus intensity, patient gender, patient age group and ear side studied.

Conclusions: This study collected extra-tympanic electrocochleography data in a normal population and the results were in the range of other international studies obtained in other countries. These data can be used as a reference to evaluate illnesses that affect cochlear structure or functions.

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∗ Corresponding author.

E-mail address: jauremar88@gmail.com (J. Redondo-Martínez).

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**PALABRAS CLAVE**
Electrocochleografía; Extratimpanica; Diagnóstico; Normalidad; Potencial de acción; Potencial de sumación; Enfermedad de Meniére

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**Electrocochleografía extratimpanica en una población normal. Estudio descriptivo**

**Resumen**

*Introducción y objetivos: La electrocochleografía extratimpanica es un registro electrophysiological que refleja la actividad eléctrica acontecida en la cóclea tras un estímulo sonoro. Se obtiene mediante la aplicación del estímulo en el conducto auditivo externo y el registro de la actividad eléctrica mediante electrodos de superficie. Dada la escasa literatura existente acerca de la exploración electrocochleográfica normal en nuestro medio, este estudio busca regularizar los valores obtenidos mediante esta exploración en sujetos sin enfermedad otonuerológica y explicar detalladamente el proceso mediante el cual se obtiene el registro.*

*Métodos: Exploración mediante electrocochleografía extratimpanica de 60 oídos sin enfermedad otonuerológica y análisis estadístico de los resultados obtenidos. De ellos, 30 oídos fueron explorados a 90 dB mientras que otros 30 oídos fueron estimulados a 80 dB.*

**Resultados:** Se muestran los valores medios de amplitud y latencia del potencial de sumación y del potencial de acción, así como las latencias medias de la onda I y la onda II. Asimismo, se presenta el cálculo del cociente potencial de sumación/potencial de acción. Obtenidos estos resultados se comparan en función de la intensidad del estímulo, del sexo del paciente, del oído estudiado y del grupo etario.

**Conclusiones:** Este estudio recopila datos sobre la electrocochleografía en una población normal. Los valores obtenidos están en el rango de los valores normales de otros países, expuestos en la literatura internacional. Estos datos pueden ser muy útiles como referencia a la hora de valorar exploraciones en pacientes con dolencias que afectan la estructura o la función coclear.

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**Introduction**

Electrocochleography is an electrophysiological test covering the short latency auditory evoked potentials which occur in the first 10–15 ms after sound stimulation. It records the electrical activity occurring in the cochlea and the auditory nerve after sound stimulation, which can be emitted in various ways, as clicks or tone burst.

Electrocochleography can be classified as transtympanic or extratympanic depending on the location of the electrodes. Given that the placement of electrodes on the promontory, necessary to achieve an intratympanic electrocochleography, is an invasive procedure, this study was undertaken using the extratympanic technique, which is considered a non-invasive test. This is why although the transtympanic technique can be more precise, have lower noise levels and achieve potentials of greater magnitude, the extratympanic technique was used because it is easy to perform, due to the speed in achieving the recording and because it is less aggressive.

The recorded wave comprises different potentials: cochlear microphones, summing potential (SP) and action potential (AP). Cochlear microphonic potentials are an alternating electrical current produced by the hair cells of the organs of Corti in which the contribution of the external cells is 10 times greater than that of the internal cells. It is a potential that is recorded after low or moderate stimuli, the phase and duration of which relate linearly with the intensity of the stimulus. The SP is continuous electrical activity which reaches its greatest amplitude in the area where the effect is recorded of the summation of potentials of a wider portion of the displacement of the basilar membrane. In practice it appears mixed with the AP. Finally, the AP corresponds to the summed response of the synchronous firing of the acoustic nerve fibres. It corresponds with the end of electromechanical transduction and with the start of the electrical activity of the auditory nerve. The SP/AP ratio can be calculated from these potentials.

The most established and best known clinical application of electrocochleography is in diagnosing and monitoring Menière’s disease. It can also be useful for intraoperatively monitoring the auditory structures during surgical procedures where there is a risk of injury. Furthermore, the study of cochlear microphonic potentials has been reported to enable a diagnosis of auditory neuropathy. It is possible that electrocochleography is also useful in some demyelinating and autoimmune diseases such as sudden hearing loss.

Although many authors agree that an SP/AP ratio greater than 0.5 is pathological and indicates the presence of endolymphatic hydrops, there is little literature on the normal values of electrocochleography that sets a clear normal limit. The parameters depend on many factors that can change the latency and amplitude of the potentials. As a consequence, the SP/AP ratio can also be variable, which makes it difficult to set a numerical limit that indicates endolymphatic hydrops. This is why many authors suggest that each centre should create their own control group to determine the normality values of electrocochleography under the working conditions used in that particular centre. On the one hand, the aim is to describe in detail the process for obtaining an electrocochleographical recording so that the results shown are useful for other testers in confirming reproducibility in...
the test and, on the other, to obtain a standard curve of electrocochleography to provide information on the normal amplitudes and latencies to enable testers to detect potentials, which is not always an easy task. The results are analysed using descriptive statistics.

There is no unanimity on the best sound intensity for performing the test. Some authors perform it exclusively at 90 dB\cite{12,13} while others perform it at various intensities in a descending manner until reaching the threshold at which wave I disappears. In our study we used intensities of 90 and 80 dB.

**Material and Methods**

The study sample comprised 60 ears. Each ear was recorded separately to undertake the calculations and the age of the subject was taken into account. A total of 30 ears were studied at 90 dB (15 left and 15 right), and 30 ears at 80 dB (13 left and 17 right). Given that this study was performed in healthy individuals, 90 dB was used as the intensity of choice, since it is a sufficiently high intensity to obtain a suitable electrical recording, without the test being uncomfortable for normal hearing subjects. In order to assess the variation of the result of the test according to the intensity of the stimulus another group was created of ears examined at a sound intensity of 80 dB, with the intention of comparing both groups with one another. The distribution of the sample according to the ear, age and gender of the sample is shown in Table 1.

A history of previous otoneurological disease and hearing loss demonstrated by liminar tonal audiometry were exclusion criteria. Subjects under the age of 15 were excluded from the study because an increase in latency has been described in subjects under this age, as their nervous system has not reached maturity.

All the cases underwent liminar tonal audiometry, the hearing thresholds were found to be below 25 dB at all the frequencies studied (250–8000 Hz). The family histories of the subjects were researched in depth, and those with a history of Menière’s disease or hereditary hearing loss were excluded.

Vivosonic Integrity 5.2® (Canada) was used for the electrocochleography. Ear adaptors with a 10 mm electrode were used (Vivosonic ER3-26B for electrocochleography). Ambu Neuroline 720 surface electrodes were used. Otoscopy confirmed the absence of cerumen in the subjects’ auditory canals. If cerumen was found, it was removed before performing the test. After thoroughly cleaning the surface electrode contact areas, the positive and negative electrodes of the evoked potential equipment were placed on both mastoids: the negative electrode was placed on the mastoid of the ear under study, and the positive electrode on the contralateral mastoid. It was checked that the impedances were below 5 k\(\Omega\) before making the recording. The test was performed using a wireless device, the subjects were awake and a Kalman filter was used. This filter is an algorithm which optimises the digital processing of the signal and substantially reduces the artefacts caused by muscular and ocular electrical activity, so that clean responses can be obtained in most patients. Theoretically it enables recordings of auditory evoked potentials in conscious, non-relaxed patients, and even in children while they are performing an activity (mothers rocking or feeding their children, children drawing or undertaking other activities). Clicks were used as the stimuli with an ER-3A transducer. All the patients were studied with a number of equivalent responses of over 400 repetitions. There was nil percentage of rejection of stimuli in each of the patients. The test was performed at 90 dB intensity in 30 ears and at 80 dB in the other 30. The following parameters were set for analysing the electrocochleography wave:

- Baseline: amplitude expressed in \(\mu\)V at which wave I starts, and which is taken as a reference to calculate the amplitudes measured subsequently.
- Start of wave I or statistical start (TI): time at which wave I starts, expressed in ms.
- End of wave I or statistical end (TE): valley posterior to wave I, time at which wave II, expressed in ms.
- SP: maximum amplitude, expressed in \(\mu\)V.
- AP: maximum amplitude, expressed in \(\mu\)V.
- The SP/AP ratio was obtained from the recorded data.
- Time until AP (Tpa): time in ms until maximum amplitude of the AP.
- Time until SP (Tps): time in ms until maximum amplitude of the SP.

**Table 1** Distribution of the Sample According to Ear, Age and Gender.

<table>
<thead>
<tr>
<th>Sample</th>
<th>At 90 dB</th>
<th>At 80 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Females</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td>RE</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>LE</td>
<td>15</td>
<td>13</td>
</tr>
<tr>
<td>15–30 years</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>30–50 years</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>&gt;50 years</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Mean age</td>
<td>39.07</td>
<td>35.7</td>
</tr>
</tbody>
</table>

Fig. 1 shows the parameters measured.

Microsoft Office Excel 2013 was used to create the database and IBM SPSS Statistics 22 software package for the statistical calculations.

Sixty ears in total were examined: 42 female and 18 male. Normality of sample distribution was estimated for each variable by the Shapiro–Wilk’s test. A non-parametric distribution of the samples was only estimated in the amplitude of the AP, and the amplitude of the SP at 90 and 80 dB. In order to compare the means of the different variables according to whether the test was undertaken at 90 or at 80 dB, the Student’s \(t\)-test was used for independent samples and Mann–Whitney’s \(U\) test for the cases where a parametric distribution of the samples could not be assumed.

In order to assess whether there were differences in the recordings according to the age of the subjects, the sample was divided into age groups as follows:

- At 90 dB: 8 ears between 15 and 30 years of age, 16 between 30 and 50 and 6 over 50.
- At 80 dB: 12 ears between 15 and 30 years of age, 13 between 30 and 50 and 5 over 50.
Figure 1  Parameters measured in the electrocochleography.

The means of each of the parameters obtained at 90 dB (SP, AP, Tps, Tpa, SP/AP, Ti, and TF) were compared in accordance with these 3 age groups. The same operation was performed with the group examined at 80 dB. The ANCOVA test was used for this and Kruskal–Wallis H test in the non-parametric distributions.

Furthermore, the means of each of the variables were compared according to the ear studied, using the new Student’s t-test for independent samples and Mann–Whitney’s U test.

Finally, the confidence intervals were calculated with a $\alpha=0.05$.

Results

The sample studied had a mean age of 39.07 years ($\sigma=11.5$) in the cases examined at 90 dB and 35.7 years ($\sigma=10.8$) in those studied at 80 dB, this difference was not found to be statistically significant ($P>0.05$).

The mean latency times of various parameters were analysed, measured in milliseconds (ms):

- Baseline of wave I (Ti): 0.49 ms ($\sigma=0.12$) at 90 dB and 0.74 ms ($\sigma=0.2$) at 80 dB.
- Maximum amplitude of the AP (Tpa): 1.44 ms ($\sigma=0.09$) at 90 dB and 1.62 ms ($\sigma=0.14$) at 80 dB.
- Maximum amplitude of the SP (Tps): 0.82 ms ($\sigma=0.13$) at 90 dB and 1 ms ($\sigma=0.2$) at 80 dB.
- End of wave I or start of wave II (Ti): 1.88 ms ($\sigma=0.17$) at 90 dB and 2.18 ms ($\sigma=0.16$) at 80 dB.

On comparing the means of the latencies obtained at 90 dB with those obtained at 80 dB, all were greater in the test at 80 dB. This curve presented some latency compared to the curve at 90 dB. These differences were statistically significant ($P<0.05$) and are shown on Table 2.

Furthermore, the mean values of the amplitude of the SP and of the AP were analysed, expressed in microvolts ($\mu V$).

- Amplitude of the SP: 0.12 $\mu V$ ($\sigma=0.11$) at 90 dB and 0.06 $\mu V$ ($\sigma=0.04$) at 80 dB.
- Amplitude of the AP: 0.45 $\mu V$ ($\sigma=0.3$) at 90 dB and 0.25 $\mu V$ ($\sigma=0.1$) at 80 dB.

On comparing the means of the amplitude of the potentials, greater amplitude of the waves was appreciated in the test at 90 dB. Therefore, there is a lower curve at 80 dB and consequently, with fewer differences in voltage. The results are shown on Table 2.

- Finally, the SP/AP ratio: its mean was 0.26 ($\sigma=0.11$) at 90 dB and 0.28 ($\sigma=0.1$) at 80 dB.

No significant difference can be appreciated on comparing the means of the SP/AP ($P>0.5$). This result is shown in Table 2.

On separating the results according to the ear studied and comparing the means obtained, no statistically significant differences were found between the left ears and the right ears. Therefore, no differences were found in either the time parameters (Ti, Tf, Tpa and Tps) or in the amplitude of the potentials (AP and SP). These results are shown in Table 3.

On dividing the ears studied according to age, no differences were found in any of the parameters studied according to age group.

The results according to age group are shown in Table 4.

With the data obtained, the confidence intervals were found with $\sigma=0.05$ for AP, SP, Tpa, Tps, SP/AP ratio, Ti and Tf. According to this estimation at 90 dB, the SP will reach its maximum between 0.77 and 0.86 ms, with an amplitude between 0.08 and 0.16 $\mu V$. The AP will reach its maximum amplitude between 1.41 and 1.47 ms, with an amplitude between 0.33 and 0.57 $\mu V$. The confidence intervals for the remaining parameters at 90 dB and all the parameters measured at 80 dB are shown in Table 5.

Thus, the mean electrocochleography curve is shown in Figs. 2 and 3, with its mean values, at 90 and 80 dB, respectively.

Discussion

Electrocochleography can be transtympanic or extratympanic depending on the site where the electrodes are placed. Some authors claim that the extratympanic technique has artefact levels due to noise above those of the transtympanic technique. Although the transtympanic technique can be more accurate and obtain potentials of greater amplitude, the extratympanic technique is used most frequently, because it is easy to undertake and is not invasive. According to most authors, electrocochleography is useful for diagnosing and monitoring the progress of patients with Menière’s disease. 

To do so, it is recommended that the SP/PA ratio is used as the parameter, either as the amplitude ratio or as the areas under the curve ratio. The latter method is somewhat more sensitive according to the
recent literature.\textsuperscript{10,25–27} Although there is no clear limit of
the SP/AP ratio value that would indicate endolymphatic hydrops, the majority of authors consider an SP/AP ratio
below 0.5 to be normal.\textsuperscript{6,23,26,27,35} However, other authors
consider this normality limit to be below 0.4.\textsuperscript{18,37} Higher
ratios would be considered suggestive of endolymphatic hydrops. It has also been pointed out that the SP/AP ratio
can vary according not only to the degree of hydrops at the
time of study, but also to the time that it has been
present.\textsuperscript{17}

The normal values of electrocochleography vary widely
depending on the technique used to obtain them (transyste-
pnic or extratympanic) and the material used.\textsuperscript{14,27} There
is little literature regarding extratympanic electrocochlear
values in healthy subjects in our environment. This study
seeks to analyse the data obtained to describe patterns of
normality so that the confidence intervals found in terms of
time and amplitude of waves enable them to be recognised
by the tester.

Some normality studies use 90 dB as the intensity of
choice for the test.\textsuperscript{6,27} Others test with a greater range of
sound intensities, from 85 to 105 dB.\textsuperscript{28} We used intensities
of 90 dB and 80 dB, because these are well tolerated by sub-
jects with no hearing loss, and enable electrocochleographic
curves to be obtained of a sufficient amplitude to interpret
them correctly.

The data obtained are similar to those of Padilla\textsuperscript{29} in a
study on the normality of the latencies of electrocochleo-
graphic events. Furthermore, Martin-Sanz\textsuperscript{27,35} presents a
mean SP/PA ratio of 0.33 in a control group of 20 healthy
ears at 90 dB. This differs little from the mean mentioned in
the results section (0.28–90 dB).

| Table 2 | Comparison Between Values Obtained at 90 dB and at 80 dB. |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Age | Tps (ms) | Tpa (ms) | SP/AP | Ti (ms) | Tf (ms) | SP (μV) | AP (μV) |
| Means at 90 dB | 39.07 | 0.82 | 1.44 | 0.26 | 0.49 | 1.88 | 0.12 | 0.45 |
| Means at 80 dB | 35.70 | 1.00 | 1.62 | 0.28 | 0.74 | 2.18 | 0.06 | 0.25 |
| T-test | 0.25 | <0.001 | <0.001 | 0.27 | <0.001 | <0.001 | Mann–Whitney U test | 0.01 | <0.001 |

| Table 3 | Comparison Between Right Ears and Left Ears. |
| --- | --- | --- | --- | --- | --- | --- | --- |
| LE means at 90 dB | 39.13 | 0.80 | 1.44 | 0.28 | 0.51 | 1.93 | LE means at 90 dB | 0.12 | 0.38 |
| LE means at 90 dB | 39.00 | 0.83 | 1.43 | 0.24 | 0.48 | 1.89 | RE means at 90 dB | 0.14 | 0.42 |
| T-test per ear at 90 dB | 0.98 | 0.64 | 0.68 | 0.48 | 0.53 | 0.29 | Mann–Whitney U test | 0.42 | 0.48 |
| RE means at 80 dB | 35.88 | 1.01 | 1.63 | 0.29 | 0.74 | 2.21 | RE means at 80 dB | 0.07 | 0.25 |
| LE means at 80 dB | 35.46 | 0.98 | 1.59 | 0.26 | 0.74 | 2.14 | LE means at 80 dB | 0.06 | 0.25 |
| T-test per ear at 80 dB | 0.92 | 0.69 | 0.48 | 0.43 | 0.93 | 0.23 | Mann–Whitney U test | 0.54 | 0.99 |

<p>| Table 4 | Comparison of Ears According to Age Group. |</p>
<table>
<thead>
<tr>
<th>Means</th>
<th>Age</th>
<th>Tps (ms)</th>
<th>Tpa (ms)</th>
<th>SP (μV)</th>
<th>AP (μV)</th>
<th>SP/AP</th>
<th>Ti (ms)</th>
<th>Tf (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15–30 years</td>
<td>26</td>
<td>0.95</td>
<td>1.57</td>
<td>0.05</td>
<td>0.18</td>
<td>0.30</td>
<td>0.68</td>
<td>2.15</td>
</tr>
<tr>
<td>30–50 years</td>
<td>37.46</td>
<td>1.01</td>
<td>1.64</td>
<td>0.08</td>
<td>0.31</td>
<td>0.28</td>
<td>0.73</td>
<td>2.20</td>
</tr>
<tr>
<td>&gt;50 years</td>
<td>54.4</td>
<td>1.1</td>
<td>1.66</td>
<td>0.05</td>
<td>0.23</td>
<td>0.22</td>
<td>0.91</td>
<td>2.18</td>
</tr>
</tbody>
</table>

| Table 5 | 95% Confidence Intervals for the Means Obtained. |
| --- | --- | --- | --- | --- | --- | --- |
| 90 dB | SP/AP | Lower Limit | Upper Limit | 80 dB | SP/AP | Lower Limit | Upper Limit |
| AP | 0.22 | 0.30 | 0.33 | 0.57 | 0.24 | 0.32 |
| SP | 0.08 | 0.16 | 0.08 | 0.16 | 0.20 | 0.30 |
| Tpa | 1.41 | 1.47 | 1.47 | 1.47 | 1.57 | 1.66 |
| Tps | 0.77 | 0.86 | 0.77 | 0.86 | 0.93 | 1.07 |
| Ti | 0.45 | 0.54 | 0.45 | 0.54 | 0.66 | 0.82 |
| Tf | 1.82 | 1.94 | 1.82 | 1.94 | 2.12 | 2.24 |
As shown in the results section, no significant differences were found between males and females or between left and right ears, at either 90 or 80 dB. Neither were any differences observed according to age group.

As would be expected, as with evoked potentials, the latency of the waves is less the more intense the sound stimulus. Similarly, the amplitude of the waves reduces as the sound stimulus lessens in intensity, due to less stimulation of the organ of Corti and, therefore, less depolarisation. All these differences between means in the latencies at 90 and at 80 dB, and the amplitudes at 90 and 80 dB are statistically significant. The only mean that does not differ statistically in the subjects tested at 90 and 80 dB is the SP/AP ratio. This finding is understandable in that the variations of the amplitudes of both waves are significant separately, but maintain a proportion; therefore their ratio maintains a similar range irrespective of the intensity at which the test is performed.

The purpose of the confidence intervals found is to establish a time window in which to search for the waves and a range of amplitudes to be expected for them. These could be used as patterns while the test is being performed so that the tester can identify these events more easily.

**Conclusions**

As is to be expected, both the AP and the SP present later in electrocochleography the lower the intensity of the sound stimulus. In turn, the amplitude of the waves is lower as the sound intensity lessens. This study compiles data on normal electrocochleography in our environment and concurs with the normal values in the international literature. These data could be useful in establishing benchmark values for healthy subjects in our environment. Obtaining a benchmark for extratympanic electrocochleography enables tests on patients with diseases affecting the cochlear structure or function to be better evaluated.

**Conflict of Interests**

The authors have no conflict of interests to declare.

**References**


