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Characteristics of Brain Signals in Response to Audiovisual Stimulation Using the Electrical Capacitance Volume Tomography (ECVT) Principle

Dewi Retno Kinasih[1*], Heni Sumarti[1], Sheilla Rully Anggita[1], Irman Said Prastyo[1], Marlin Ramadhan Baidillah[2], Harisma Nugraha[3], and Rohmadi[3]
[1] Department of Physics, Faculty of Science and Technology, Universitas Islam Negeri Walisongo Semarang, Indonesia
[2] Department Research Center for Electronics, National Researchand Innovation Agency, Indonesia
[3] Cancer Research Center, PT. C-Tech Lab Edwar Teknologi, Indonesia
*Corresponding author's e-mail: 2108026036@student.walisongo.ac.id

ABSTRACT

The human brain continuously generates electrical activity that changes measurably when it processes external stimuli. Electrical Capacitance Volume Tomography (ECVT) is a non-invasive, radiation-free volumetric sensing technique that has been adapted, as a helmet-shaped capacitive sensor, to monitor human brain electrical activity in real time. This study characterizes the ECVT-based brain signal response to audiovisual stimulation and identifies the measurement frequency and sensor-channel combination most sensitive to stimulus-related change. A single healthy male subject (21 years old) was measured using a 16-sensor ECVT helmet connected to an Arbitrary Function Generator and an oscilloscope. Peak-to-peak voltage (Vpp) was recorded for six representative sensor-channel pairs at three carrier frequencies (500 kHz, 1 MHz, and 5 MHz) under three conditions – audiovisual (video and music) stimulation, a water-filled helmet reference, and an empty (air-filled) helmet reference – with six repeated measurements per combination. Across the three frequencies, the 500 kHz measurements showed the most pronounced differences between channels and between conditions, while the 1 MHz and 5 MHz measurements showed comparatively little variation. At 500 kHz, channel responses during audiovisual stimulation were visibly more variable than during the water-filled or empty reference conditions. Among the tested frequencies, 500 kHz was the most sensitive for detecting ECVT signal changes associated with audiovisual stimulation, indicating that both operating frequency and channel selection are important considerations for ECVT-based studies of brain responses to sensory stimulation.

Keywords:
Electrical Capacitance Volume Tomography; Brain Signal; Audiovisual Stimulation; Non-Invasive Brain Imaging; Frequency Response

Introduction

The human brain continuously generates electrical activity as networks of neurons communicate, and this activity changes measurably when the brain processes external sensory input. Capturing these changes non-invasively, in real time, and without exposing the subject to ionizing radiation remains an important goal for neuroscience and medical-physics instrumentation.

Electrical Capacitance Volume Tomography (ECVT) is one technique developed toward this goal. ECVT reconstructs the volumetric distribution of electrical permittivity inside a sensing domain from capacitance measurements taken by an array of electrodes surrounding it, without the layered image-stacking process used in conventional tomography (Warsito et al., 2007; Wang et al., 2010). Because ECVT relies on electric-field measurement rather than ionizing radiation, it can, in principle, be operated safely and repeatedly on human subjects. Adapted into a helmet-shaped sensor placed on the scalp, ECVT has been used to detect electrical signals associated with human brain motor and language activity in real time (Taruno et al., 2013), and the same instrument has since been used to investigate brain responses to specific stimuli, including music, by comparison with simultaneous EEG recordings (Handayani et al., 2015), as well as in diagnostic applications such as brain tumor detection (Maharani et al., 2020).

Audiovisual media, which combine sound and moving images, are widely used as controlled stimuli because they are easy to standardize and are known to produce measurable psychological and physiological responses. Audiovisual stimulation has been reported to reduce anxiety during medical procedures in children (Fatmawati et al., 2019) and to improve learning outcomes compared with non-audiovisual instruction (Windasari & Syofyan, 2019); such effects are consistent with the broader description of audiovisual media as a combined sound-and-image format distributed through film, television, and digital platforms (Munandar & Tambunan, 2018). These findings support audiovisual stimulation as a practical, standardizable way to evoke a measurable brain response.

While ECVT-based brain scanning has previously been used to examine responses to stimuli such as music (Handayani et al., 2015) and to motor or language tasks (Taruno et al., 2013), its response to combined audiovisual stimulation, and the influence of measurement frequency on the sensitivity of that response, has not been reported. This is relevant because ECVT is operated at a selectable carrier frequency, and the choice of frequency and sensor-channel pair may affect how clearly a stimulus-related signal can be distinguished from the sensor's baseline behavior.

This study, conducted during practical work (Kerja Praktik) at PT Ctech Lab Edwar Teknologi, characterizes the brain signal recorded by a 16-sensor ECVT helmet in response to audiovisual stimulation and compares the response across three carrier frequencies (500 kHz, 1 MHz, and 5 MHz) against water-filled and empty helmet reference conditions, in order to identify a measurement frequency and channel combination that is most sensitive to audiovisual-stimulus-related changes in the recorded brain signal.

Methods

Subject

Measurements were carried out on a single healthy male subject, 21 years old. During each measurement the subject sat in a relaxed position with the feet placed on an insulating support to avoid a ground connection, and did not hold any object.

Tools and Materials

The equipment used comprised a laptop computer; a 16-sensor Electrical Capacitance Volume Tomography (ECVT) helmet; an Arbitrary Function Generator (AFG); an oscilloscope; a Hantex unit; a T-connector; a BNC connector; connecting cables; and spreadsheet software (Microsoft Excel and Google Spreadsheets) for recording and processing the measurement data. All instruments were assembled and calibrated prior to data collection to ensure consistency and accuracy.

Data Acquisition Procedure

Data were obtained by direct measurement of the subject described above. The subject sat in a relaxed position while the ECVT helmet was placed on the head; a pair of channels was then selected for the carrier-signal cable and for the signal cable captured by the oscilloscope. Measurements were repeated at three carrier frequencies – 500 kHz, 1 MHz, and 5 MHz. At each frequency the subject was measured under three conditions: (1) audiovisual stimulation, consisting of a high-contrast video accompanied by pop music played on a continuous loop; (2) a reference condition with the ECVT helmet filled with water; and (3) a reference condition with the ECVT helmet empty (air-filled). As reported in the original field records, the audiovisual condition was repeated three times on the subject and the helmet-only reference conditions were repeated two times, each repetition lasting three minutes; the tables in the Results section report the individual readings obtained during these repetitions. Voltage data were saved by the oscilloscope as ".txt" files and subsequently processed using spreadsheet software (Google Spreadsheets) to tabulate and plot the peak-to-peak voltage (Vpp) recorded at each sensor-channel pair.

Sensor Channels

The ECVT helmet used in this study has 16 sensors, from which multiple sensor-channel pairs can be formed. This report presents peak-to-peak voltage (Vpp) results for six representative channel pairs – 3_2, 3_4, 3_11, 7_6, 7_8, and 7_15 – selected from the recorded dataset.

Results and Discussions

Result

Table 1 through Table 9 present the peak-to-peak voltage (Vpp, in volts) recorded for six sensor-channel pairs (3_2, 3_4, 3_11, 7_6, 7_8, and 7_15) of the ECVT helmet, across three carrier frequencies (500 kHz, 1 MHz, and 5 MHz) and three conditions (audiovisual stimulation, water-filled helmet, and empty helmet), with six repeated readings recorded for each combination.

Table 1. Peak-to-Peak Voltage (Vpp, in V) at 500 kHz – Audiovisual Stimulation

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.951	9.939	9.914	9.995	10.014	10.014
2	9.958	9.933	9.933	10.002	10.014	10.014
3	9.951	9.932	9.901	9.995	10.014	10.033
4	9.958	9.927	9.914	9.998	10.008	10.014
5	9.958	9.939	9.914	10.005	10.008	10.02
6	9.958	9.782	9.914	10.002	10.008	10.008

Table 2. Peak-to-Peak Voltage (Vpp, in V) at 500 kHz – Water-Filled Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.672	9.727	9.638	9.722	9.719	9.711
2	9.672	9.719	9.683	9.719	9.719	9.716
3	9.667	9.727	9.680	9.722	9.719	9.715
4	9.854	9.704	9.854	9.726	9.879	9.867
5	9.857	9.704	9.848	9.726	9.886	9.726
6	9.857	9.700	9.704	9.722	9.732	9.876

Table 3. Peak-to-Peak Voltage (Vpp, in V) at 500 kHz – Empty (Air) Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.672	9.727	9.638	9.722	9.719	9.711
2	9.672	9.719	9.683	9.719	9.719	9.716
3	9.667	9.727	9.680	9.722	9.719	9.715
4	9.854	9.704	9.854	9.726	9.879	9.867
5	9.857	9.704	9.848	9.726	9.886	9.726
6	9.857	9.700	9.704	9.722	9.732	9.876

Tables 1 to 3 show the results of measurements at 500 kHz for the audiovisual, water-filled, and empty helmet conditions, respectively. The results indicate a difference at channel 3, most clearly seen when the audiovisual condition is compared against the water-filled reference.

Table 4. Peak-to-Peak Voltage (Vpp, in V) at 1 MHz – Audiovisual Stimulation

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.813	9.788	9.757	9.845	9.87	9.863

No.	3_2	3_4	3_11	7_6	7_8	7_15
2	9.82	9.776	9.769	9.848	9.87	9.864
3	9.807	9.788	9.763	9.845	9.87	9.87
4	9.813	9.788	9.763	9.848	9.87	9.846
5	9.807	9.776	9.763	9.848	9.857	9.846
6	9.801	9.782	9.757	9.842	9.876	9.864

Table 5. Peak-to-Peak Voltage (Vpp, in V) at 1 MHz – Water-Filled Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.672	9.727	9.638	9.722	9.719	9.711
2	9.672	9.719	9.683	9.719	9.719	9.716
3	9.667	9.727	9.680	9.722	9.719	9.715
4	9.854	9.704	9.854	9.726	9.879	9.867
5	9.857	9.704	9.848	9.726	9.886	9.726
6	9.857	9.700	9.704	9.722	9.732	9.876

Table 6. Peak-to-Peak Voltage (Vpp, in V) at 1 MHz – Empty (Air) Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	9.859	9.859	9.866	9.862	9.862	9.870
2	9.859	9.859	9.862	9.862	9.862	9.870
3	9.862	9.862	9.862	9.859	9.862	9.870
4	9.859	9.862	9.862	9.862	9.862	10.027
5	9.863	9.859	9.862	9.862	9.862	10.027
6	9.863	9.862	9.866	9.862	9.862	10.024

Tables 4 to 6 show the results of measurements at 1 MHz. Across the three conditions, the readings for each channel pair are close to one another, indicating little variation in Vpp with the treatment applied to the subject at this frequency.

Table 7. Peak-to-Peak Voltage (Vpp, in V) at 5 MHz – Audiovisual Stimulation

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	8.408	8.533	8.358	8.455	8.464	8.452
2	8.383	8.383	8.358	8.446	8.458	8.596
3	8.245	8.383	8.213	8.439	8.471	8.471
4	8.383	8.383	8.364	8.446	8.464	8.458
5	8.402	8.383	8.358	8.439	8.471	8.464
6	8.389	8.383	8.37	8.439	8.471	8.446

Table 8. Peak-to-Peak Voltage (Vpp, in V) at 5 MHz – Water-Filled Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	8.179	8.301	8.326	8.326	8.32	8.329
2	8.182	8.314	8.320	8.320	8.32	8.336
3	8.195	8.301	8.320	8.182	8.32	8.333

No.	3_2	3_4	3_11	7_6	7_8	7_15
4	8.176	8.314	8.195	8.336	8.455	8.213
5	8.317	8.301	8.191	8.194	8.455	8.359
6	8.176	8.323	8.330	8.334	8.459	8.355

Table 9. Peak-to-Peak Voltage (Vpp, in V) at 5 MHz – Empty (Air) Reference

No.	3_2	3_4	3_11	7_6	7_8	7_15
1	8.453	8.453	8.610	8.603	9.862	8.466
2	8.45	8.458	8.458	8.458	9.862	8.458
3	8.45	8.455	8.458	8.458	9.862	8.458
4	8.607	8.459	8.459	8.455	9.862	8.459
5	8.612	8.454	8.454	8.455	9.862	8.619
6	8.455	8.459	8.459	8.463	9.862	8.462

Tables 7 to 9 show the results of measurements at 5 MHz. As with 1 MHz, the readings across the three conditions do not differ substantially between channels, indicating little variation in Vpp with the treatment applied to the subject at this frequency.

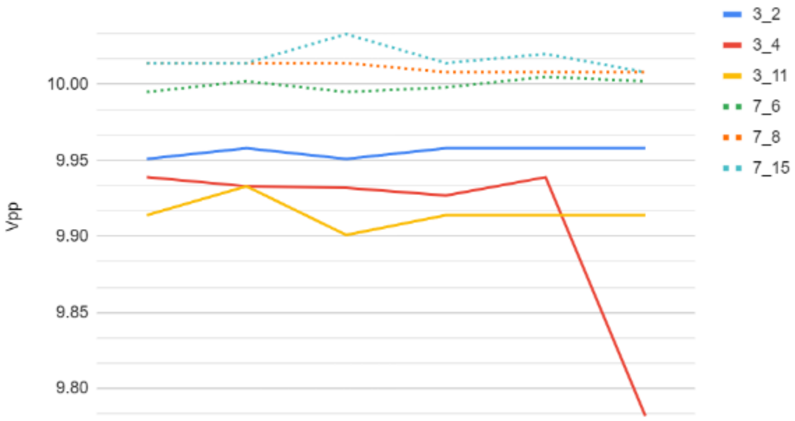

Figure 1. ECVT Channel Response during Audiovisual (Video) Stimulation at 500 kHz

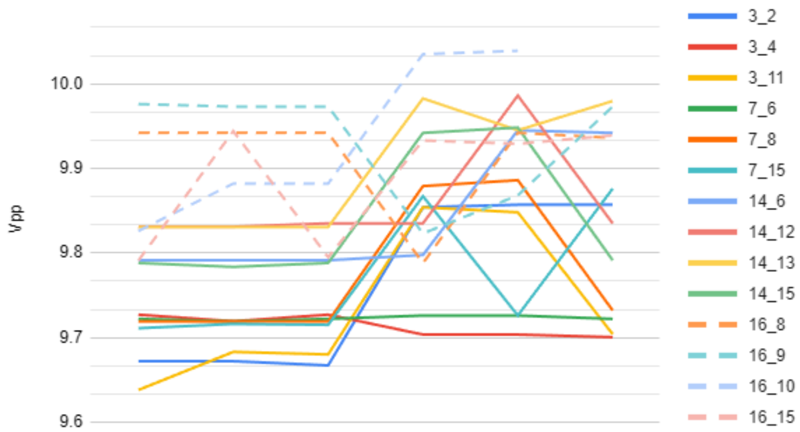

Figure 2. ECVT Channel Response during the Water-Filled Reference Condition at 500 kHz

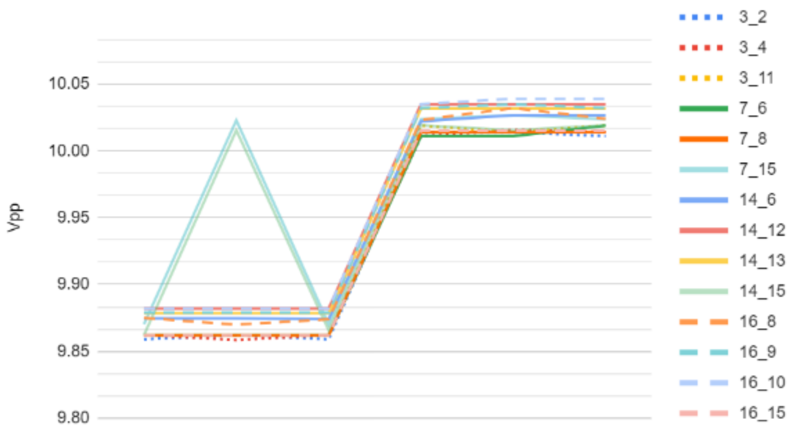

Figure 3. ECVT Channel Response during the Empty (Air) Reference Condition at 500 kHz

Figures 1 to 3 compare the channel response at 500 kHz under the audiovisual, water-filled, and empty conditions. There is a visible difference in the pattern of response between conditions, which illustrates the importance of channel selection for obtaining a clear result in ECVT-based measurement of brain signal. Under audiovisual stimulation, the responses of the six channel pairs are more variable and less tightly grouped than under the water-filled or empty conditions, in which the channel pairs largely track one another.

Discussion

Based on the data obtained for each channel and audiovisual activity performed by the subject, the recorded values were imported and processed using spreadsheet software. From this data, plots were generated to identify the frequency and channel combination most sensitive among the three tested frequencies (500 kHz, 1 MHz, and 5 MHz) and the channel-pair combinations 2–3, 4–3, and 11–3, compared against 6–7, 8–7, and 15–7. Under audiovisual stimulation, the water-filled condition, and the empty (air) condition, the resulting Vpp values were noticeably more variable at 500 kHz than at the two higher frequencies. This suggests that, within the range tested, brain-related signal changes were more readily detected at the lower carrier frequency.

The analysis further indicated that, at 500 kHz, the combination of channels showed a more pronounced difference between conditions than at 1 MHz or 5 MHz, consistent with the pattern seen in Tables 1–3 and Figures 1–3. This is consistent with prior use of the 4D Brain ECVT instrument to detect brain electrical activity associated with external stimuli such as music (Handayani et al., 2015) and motor or language tasks (Taruno et al., 2013), and extends that body of work to audiovisual stimulation while additionally comparing sensitivity across carrier frequencies.

Because ECVT senses brain activity indirectly, through changes in the electrical permittivity distribution captured as capacitance at the helmet electrodes (Warsito et al., 2007; Wang et al., 2010), the carrier frequency used to interrogate the sensor can be expected to affect how clearly a stimulus-related change is resolved against the sensor's baseline response, which is consistent with the comparatively flat readings observed at 1 MHz and 5 MHz in this study.

This study has several limitations that should be considered when interpreting the results. Measurements were obtained from a single subject without formal statistical hypothesis testing, so the differences described here should be read as observed patterns in the recorded data rather than as statistically confirmed effects; replication with a larger number of subjects and repeated trials would be needed to establish the reliability and generalizability of the 500 kHz sensitivity finding. In addition, the six channel pairs reported here are a subset of the sensor combinations available from the 16-sensor helmet, and the water-filled and empty reference conditions were used as practical baselines rather than as calibrated standards.

Conclusion

This study characterized the brain signal recorded by a 16-sensor ECVT helmet in response to audiovisual stimulation, compared against water-filled and empty reference conditions, across three carrier frequencies. The results show that ECVT-based measurement was able to capture differences in peak-to-peak voltage (Vpp) across sensor-channel pairs that corresponded to the audiovisual, water-filled, and empty conditions. Among the three frequencies tested, 500 kHz produced the most pronounced variation between channels and between conditions, while 1 MHz and 5 MHz showed comparatively little variation, indicating that 500 kHz was the most sensitive of the three frequencies for detecting audiovisual-stimulus-related changes in brain signal with this instrument. These findings indicate that both the operating frequency and the sensor-channel pair selected are important considerations for future ECVT-based studies of brain responses to sensory stimulation.

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Conflicts of interest

The authors affirm that they have no conflicts of interest.

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