









## 5. PROTOTYPING

The prototyping phase included evaluation by five users; three males and two females. Most users were able to distinguish EEG frequency changes as a result of the modulation process. Users did indicate that using a sample file of sound they were very familiar with, helped them to quicker understand the sonification process. For example, one user could not distinguish much difference with a sample file that was a bell sound, but was able to pick up on subtle frequency changes with a sound sample that was a snippet of a song he knew very well. While wearing headphones, users were also able to hear the location from where a particular modulated EEG signal was coming from, indicating the virtual placement of the sensors.

## 6. DISCUSSION

We presented BSoniq, which uses multi-channels to sonically represent EEG data in real-time 3D space using frequency modulation. BSoniq could be used for both online and offline sonification. By applying filters and parameter controls, it is possible for the user to focus on the area of interest within the signal. This is useful for real-time applications like EEG monitoring or EEG feedback. The inclusion of 360 degrees spatial cues permits the parallel sonification of many or all electrodes without losing clarity in the display. Clarity of the sonification, however also depends on the strength of the EEG signal capture from the device. The signal could also contain artifacts, which could be reduced or removed in order to yield a clearer signal for the display. What also needs to be noted is that the perceptual capabilities of the listener is important. If the listener is unable to distinguish sounds or incapable of hearing certain frequencies, then this would affect the user's perception of the installation's functionality.

Future work includes conducting additional evaluations for necessary design improvements as well as upgrading BSoniq to include other popular EEG devices. The current installation only allows for the user to remain stationary. Allowing the user's head movement and tracking, is a feature that will be added to create a fully integrated system.

To conclude, we believe we accomplished our goal of EEG sonification using 3D spatial cues. Even though BSoniq started out as an installation, mainly for an aesthetic user listening experience, we also believe that in addition to sonification, the visualization component could also be enhanced into an artistic EEG visualization application using geometric data and transformations for artistic applications. That is, exploring methods that uses OpenGL for example, to create 3D spatial-spectral representations of an EEG signal.

## 7. REFERENCES

[1] Thomas Hermann, Andy Hunt and John Neuhoff. "Auditory Display and Sonification". *The Sonification Handbook*, 2011.

[2] Gen Hori and Tomasz M. Rutkowski. "Brain listening—a sound installation with EEG sonification". *Journal of the Japanese Society for Sonic Arts*, 4(3):4–7, 2000.

[3] Thomas Hermann and Helge Ritter. "Listen to your data: Model-based sonification for data analysis". *Advances in intelligent computing and multimedia systems*, 8:189–194, 1999.

[4] Stephen Barrass and Gregory Kramer. "Using sonification". *Multimedia systems*, 7(1):23–31, 1999.

[5] Emil Jovanov, Dusan Starcevic, and Vlada Radivojevic. "Perceptualization of biomedical data". IN *MEDICINE*, page 189, 2001.

[6] Teruaki Kaniwa, Hiroko Terasawa, Masaki Matsubara, Tomasz M Rutkowski, and Shoji Makino. "EEG auditory steady-state synchrony patterns sonification". In *Signal & Information Processing Association Annual Summit and Conference (APSIPA ASC)*, 2012 Asia-Pacific, pages 1–6. IEEE, 2012.

[7] Tomasz M Rutkowski. "Multichannel EEG sonification with ambisonics spatial sound environment". In *Asia-Pacific Signal and Information Processing Association, 2014 Annual Summit and Conference (APSIPA)*, pages 1–4. IEEE, 2014.

[8] Tomasz M Rutkowski, Francois Vialatte, Andrzej Cichocki, Danilo P Mandic, and Allan Kardec Barros. "Auditory feedback for brain computer interface management—an EEG data sonification approach". In *Knowledge-Based Intelligent Information and Engineering Systems*, pages 1232–1239. Springer, 2006.

[9] Timothy Schmele and Imanol Gomez. "Exploring 3d audio for brain sonification". In *International Conference of Auditory Display*, 2012.

[10] Haracio Tome-Marques and Bruce Pennycook. "From the unseen to the s[cr]een eshofuni, an approach towards real-time representation of brain data". 2014.

[11] A Väljamäe, T Steffert, S Holland, X Marimon, R Benitez, S Mealla, A Oliveira, and S Jordà. "A review of real-time EEG sonification research". In *International Conference of Auditory Display*, 2013.

[12] Neuroscience For Kids. (n.d.), from <<http://faculty.washington.edu/chudler/1020.html>> Retrieved February 10, 2016.

[13] Walker, Bruce, and Nees, Michael. "Theory of sonification." *The Sonification Handbook*: 9-39, 2011.

[14] Emotiv EPOC EEG. <<https://www.emotiv.com>>. Retrieved July 13, 2015.

[15] Gerold Baier, Thomas Hermann, and Ulrich Stephani. "Multi-channel sonification of human EEG". In *Proceedings of the 13th International Conference on Auditory Display*, 2007.

[16] Max/MSP/Jitter Graphic software development environment. Cycling '74. <[www.cycling74.com](http://www.cycling74.com)>. Retrieved November 3, 2016.



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