UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO

FACULTAD DE INGENIERÍA

Quantification of Sensorimotor Skills and Psychophysiological Activation in Deaf Subjects Using Musical Stimuli

ARTÍCULO ACADÉMICO

Que para obtener el título de

Ingeniero en Sistemas Biomédicos

P R E S E N T A

Fernando Uristy Osornio García

ASESOR DE ARTÍCULO ACADÉMICO

Dr. Luis Jiménez Ángeles

Ciudad Universitaria, Cd. Mx., 2022

Quantification of Sensorimotor Skills and Psychophysiological Activation in Deaf Subjects Using Musical Stimuli

Miguel Alberto Martínez-Luna[1#], Fernando Uristy Osornio García[1#],
Dra. Coral Italú Guerrero-Arenas[1] Dr. Guillermo Hernández-Santana[2] Dr. Leonardo Borne[3] Dr. Luis Jiménez-Angeles[1]

***Abstract*—**Musical activities have been shown to be effective tools for the acquisition of sensorimotor (SMS) and cognitive skills, especially in deaf subjects. The aim of this research was to compare the SMS and psychophysiological state of 11 Deaf adult volunteers (27±9.3 years old) with respect to a group of 18 hearing (30.18±10.22 years old). SMS was explored using a mobile application that plays a specific rhythm while the subject identifies its respective pattern. The psychophysiological state (PsyS) was assessed by quantifying changes in indices derived from the processing of heart rate variability (HRV) and electrodermal activity (EDA) signals. SMS was explored using a mobile application that plays a specific rhythm while the subject identifies its respective pattern. At the same time, we quantify changes in PsyS. We identified that changes in the PsyS are most sensitively detected by indices derived from EDA signal analysis.

***Key Words*—**Sensorimotor skills; Deaf people; Musical tasks; Biosignals

Introduction

Sensorimotor skills (SMS) are sequences of movements that develop from temporal anticipations by coordinating the motor and auditory systems (Patel & Iversen 2014; Van Der Steen & Keller, 2013). In addition, this type of audiovisual stimulation can elicit responses sensitive to changes in the acoustic parameters of the music (Chuen, 2016, Sokhadze, 2007). These responses can be quantifiable by physiological measurements. We show the analysis of SMS and the psychophysiological states (PsyS) determined by indices computed from heart rate variability (HRV) and electrodermal activity (EDA) signals, in a set of Deaf people (DP) compared to a control group of hearing people (HP) while executed musical-based tasks. Based on previous studies that have explored the SMS, HRV, and EDA in hearing people, we addressed the research with the following questions: (1) Are the SMS in deaf different from the hearing people? (2) Are there differences between Deaf and hearing individuals in their PsyS to performing musical tasks?

Method Description

A) Design

A pilot and exploratory study is presented in which 11 DP (7 women and 4 men; mean age=30.18±10.23 years old) and 18 HP (9 men and 9 women mean age=27.87±9.30 years old) volunteers agree to participate. The etiology of hearing loss was not collected. All Deaf participants reported knowledge of Mexican Sign Language. None of the participants were using any hearing aid or cochlear implant at the time of the study. Participation in the study was voluntary and there were no incentives to participate. All participants signed a written consent form.

B) Stimuli presentation

We design an auditory paradigm composed of three musical stimuli (T1 of 24 seconds, T2 of 21 seconds, and T3 of 31 seconds) selected from a set of popular musical songs ranging from lower to higher rhythmic and speed (tempo) complexity. All tasks had a recovery time of 59 seconds after each and a baseline period of 165 seconds when non-activities were executed by subjects preceding the stimuli presentation.

A specific digital mobile app (*RhynGo App*) was designed to consecutively present the paradigm using an Android smartphone. In the app, all subjects must identify audio and visual patterns of the musical notes and press a digital

[1] Miguel Alberto Martínez Luna, Fernando Uristy Osornio García, Dra. Coral Italú Guerrero-Arenas and Dr. Luis Jiménez-Angeles are from the Department of Biomedical Systems, Engineering Faculty, UNAM, Mexico City. miguem.luna31@gmail.com, fernandofuog@gmail.com, coral.guerrero@ingenieria.unam.edu, luis.jimenez@comunidad.unam.mx (corresponding author)
[2] Dr. Guillermo Hernández-Santana is a Professor of Linguistics at the National School of Anthropology and History (ENAH-INAH), and a member of the Academy of Mexican Sign Language, Mexico City. guillermo_hernandez@inah.gob.mx
[3] Dr. Leonardo Borne is a Full-time Professor at the Department of Arts - Universidade Federal de Mato Grosso, Brazil. leo@ufmt.br
[#] These authors contributed equally.

button on the screen following the rhythm of the task. In this way, the note is destroyed and scored to record a score per task, as shown in Figure 1. The criteria of design were that a better score would be a better SMS of the subject. Also, the app had a timeout with loading screens and animations, with the aim of returning participants to their baseline physiological recording. The time of use of the application was 5 minutes. The *RhynGo App* was developed in the C# programming language and integrated into the Unity development platform for ease of use and subsequently exported to run on any Android device as a normal application.

A **B**

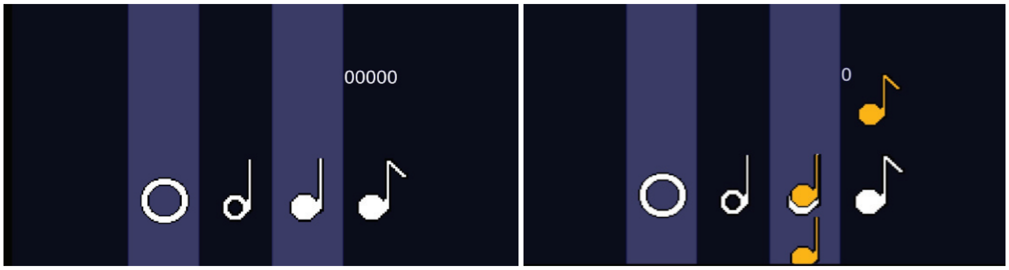

Figure 1. A) *RhynGo App* display and digital buttons, B) During the execution of a musical task and the recording of notes by means of a digital button.

C) Biosignals acquisition and processing

While subjects were stimulated by the paradigm described above, they used the *RhynGo App,* and simultaneously electrocardiogram (ECG) and electrodermal activity (EDA) signals were acquired using the physiological computing platform BITalino (r)evolution ® with a sampling rate of 1000 Hz. Changes in the indices computed from ECG and EDA signals were considered as biomarkers of the PsyS. Mean heart rate (MHR), the standard deviation of HR, and indices of heart rate variability (HRV) were computed from the ECG signals (mean of NN intervals, MeanNN; the standard deviation of NN intervals, SDNN; root mean square of successive RR interval differences, RMSSD; the standard deviation of the successive difference between NN intervals, SDSD; the proportion of successive NN intervals that are larger than 50 ms, pNN50; and the ratio of normalized low frequency to high-frequency power spectrum (LFHFn). Indices from EDA signal processing like skin conductance response (SCR), non-specific skin conductance response (NS_SCR), skin conductance level (SCL), time-invariant spectral power analysis (EDA_Symp), and normalized power of the 0.045 to 0.25 Hz range (EDA_SympN) were computed.

Summary of Results

To make an exploration of the SMS, the score of each of the tasks in the paradigm was extracted. An Anderson-Darling normality test of the scores was performed to validate the statistical method of analysis. This test showed that none of the score datasets obtained for any of the levels complied with a normal distribution. Therefore, nonparametric Mann-Whitney's tests were conducted with a confidence level of 95% to compare the median scores between groups. As for the score, at T1 non-significant differences were found between DP and HP (median = 415 and IQR = 30 vs median = 420 and IQR = 6.5; respectively). Regarding T2 also non-significant differences were found between the DP and HP (median = 580 and IQR = 60 vs median=600 and IQR=40; respectively). With respect to T3, non-significant difference was found in the scores between DP and HP (median = 360; IQR = 130 vs median= 635 and IQR=45; respectively). In all comparisons, we consider a statistical significance threshold of $p<0.05$.

Analysis of HRV and EDA records

Table 1 shows the indices of HRV and EDA for DP and HP groups per task. Statistical comparisons were performed considering two factors: Group (DP and HP) and Task (Baseline, T1, T2, T3). Non-parametric comparisons between and intra groups were computed using Wilcoxon rank and U-Mann-Whitney's tests considering a significance value of $p<0.05$. Non-significant differences were found in the parameters associated with HRV intra groups and inter tasks. Significant differences were observed in the SCL (Skin Conductance Level) and EDA_Symp parameters, the former associated with the tonic component of electrodermal activity and the latter as the spectral power analysis within the signal.

The SCL index of the DP group was significantly lower than the computed for the HP group per each task. It means SCL was the most sensitive index to detect differences in PsyS between groups while executing a musical task. For the EDA_Symp index, significant differences were found for T3 between the HP group and the DP group. However, within the DP group, there was a lower value than the HP group in all tasks, although there were significant differences only at T3.

NS_SCR (non-specific skin conductance response) is associated with the presentation of auditory stimuli without a precise synchronization between the time of the stimulus and the conductance response. Its index decreased significatively when a subject (DP or HP) performed any musical task. It means that NS_SCR, independently of the group condition, was the most sensitive index to distinguish between all tasks versus the baseline.

Indices derived from HRV and EDA analysis

Deaf People (DP)

Feature	Baseline	Task 1 (T1)	Task 2 (T2)	Task 3 (T3)
HRV_MeanNN	818.5 (721.9-850.4)	781.3 (679.9-865.6)	733.4 /666.1-881.1)	775.7 (664.2-820.4)
HRV_SDNN	59.79 (52.07-62.13	55.55 (35.78-62.45)	52.85 (43.39-71.58)	54.09 (36.92-76.96)
HRV_RMSSD	40.78 (22.61-71.87)	35.03 (25.51-53.59)	36.474 (27.08-59.74)	34.26 (24.05-60.87)
HRV_SDSD	40.87 (22.66-72)	35.14 (25.65-53.92)	36.67 (27.17-60)	34.37 (24.21-61.14)
HRV_pNN50	22.96 (2.93-34.75)	9.56 (3.84-30.98)	14.28 (6.95-23.22)	12.82 (2.83-32.08)
Mean_HR	73.37 (70.81-83.18)	76.81 (69.4-88.53)	82.01 (68.12 - 90.66)	77.35 (73.18-90.57)
Std_HR	5 (4.33-6.008)	4.59 (3.86-4.83)	5.45 (4.30-6.47)	5.13 (3.57-9.28)
HRV_LFHFn	2.02 (1.40-2.56)	1 (0.68-1.80)	2.15 (0.72-2.41)	1.23 (0.39-3.18)
SCL	8.02 (6.48-11.20)	7.64 (6.72-13.73) +	8.60 (7.77-13.78) +	8.41 (7.29-13.94) +
NS_SCR	18 (12-22)	7 (7 -12) *	9 (6-10) *	9 (7-12) *
EDA_Symp	5.45 (3.21-39.58)	7.41 (3.96-24.36)	11.97 (3.60-18.96)	3.64 (0.93-18.64) +
EDA_SympN	0.010 (0.005-0.011)	0.009 (0.004-0.01)	0.005 (0.003-0.01)	0.009 (0.004-0.01)

Hearing People (HP)

Feature	Baseline	Task 1 (T1)	Task 2 (T2)	Task 3 (T3)
HRV_MeanNN	775.1 (677.1-878.5)	767.4 (688.4-830.8)	781.5 (702.02-827.8)	768.1 (659.7-809.5)
HRV_SDNN	63.05 (44.43-79.02)	61.09 (31.98-77.89)	53.59 (42.39-80.68)	57.91 (38.01-89.98)
HRV_RMSSD	47.36 (26.97 -72.82)	45.67 (23.56-61.65)	38.52 (26.81-57.27)	45.60 (22.87-101.75)
HRV_SDSD	47.45 (27.03 - 72.95)	46.03 (23.69-62.005)	38.77 (26.92-57.59)	45.97 (22.99-102.56)
HRV_pNN50	23.67 (5.53 - 36.13)	31.51 (2.08-42.33)	16.77 (5.48-42.13)	21.04 (3.07-36.36)
Mean_HR	77.47 (68.34- 88.70)	78.23 (72.24-87.3)	76.87 (72.5-85.61)	78.16 (74.17-91.16)
Std_HR	5.89 (4.29-7.94)	5.792 (4.1-6.06)	5.15 (4.13-6.87)	5.42 (4.65-8.03)
HRV_LFHFn	2.01 (1.48-3.55)	0.9 (0.30-2.26)	1.21 (0.36-4.29)	0.51 (0.31-1.70)
SCL	9.76 (8.31-16.98)	14.27 (10.51-19.37)	14.03 (10.74-19.81)	14.68 (10.55-20.41)
NS_SCR	19.5 (16.25-27)	9.5 (6.25-11.75) *	8 (6 - 11) *	9.50 (6-11) *
EDA_Symp	16.13 (7.58-67.25)	23.33 (8.4-74.41)	26.23 (7.53- 75.47)	40.04 (16.05-100.37)
EDA_SympN	0.01 (0.01-0.02)	0.01 (0.006 -0.01)	0.01 (5.92-2.07)	1.42 (5.83-2.55)

Table 1. Indices derived from HRV, and EDA are reported. (*) Refers to statistically significant differences between the task with respect to the baseline within the same group ($p<0.05$); (+) means statistically significant differences of the task between groups ($p<0.05$).

Final Comments

We studied the relationship between the performance of music-based sensorimotor synchronization tasks and changes in a psychophysiological state associated with this activity, between Deaf and hearing individuals. Our analysis does not show significant differences in each of the task scores between DP and HP, which indicates that both groups have a similar performance to execute sensorimotor tasks no matter the deafness or hearing condition, which is concordant with the Iversen findings (2015). However, differences were found in the psychophysiological state when performing the musical tasks in the app. Reinforcing this argument, Herbert (2015) reported physiological changes when playing video games under conditions of sound and silence and observed that sound/music was an important factor in generating a greater psychophysiological response. In our research, the conditions were similar but because of the groups, Deaf and hearing people. Chuen (2016) has even related certain acoustic features to changes in psychophysiological states, e.g., in HVR and EDA when listening to variations in speed (tempo) or rhythm within a musical stimulus. In our results, no changes in HRV were observed, from which it can be inferred that the tasks may not have been challenging enough to elicit a response associated with emotional arousal and that can be recorded by HRV.

EDA Response

Our results show that there are differences between deaf and hearing individuals in their psychophysiological responses when executing music-based tasks. Especially we found that indexes computed from EDA (NS_SCR, SCL, and EDA_Symp) were significantly sensitive to distinguish groups when executing music-based tasks. EDA refers to changes in the electrical properties of the skin and is used as an indicator for processing cognitive activity as well as related emotional states (Dawson, 2001). One of its most common components is Skin Conductance Level (SCL), which appears to reflect changes in autonomic arousal. That is, it is related to a level of brain activation modulated by the reticular formation, involved in attention and wakefulness processes (Posada-Quintero et al., 2018). In this case, it was observed that the SCL index was higher in all tasks for the HP than for the DP, as well as the EDA_Symp values for T3 were also higher for the hearing individuals compared to the DP. Perhaps the increase in the SCL values is an indicator that the HP was recruiting greater attentional resources while executing the musical tasks in comparison with the DP, elevating to a certain extent the level of stress reflected in an increase in the activity of the sweat glands and that perhaps this control in the attention was modulated by the auditory input. This does not mean that the HPs would not have had attentional control, but perhaps they make use of other resources that are not recordable in the SCL parameters. Additional data or measurements in a larger population would be required to have more certain evidence, The increase in EDA_Symp values may be associated with the cognitive and physical changes (Posada-Quintero et al., 2020; Posada-Quintero et al., 2018) presented in the processing of the stimuli between the two groups. The values between groups presented changes between T1 and T2 although there were no significant differences, this could be associated with the level of difficulty of each of the tasks, although it is not conclusive. However, there were differences for T3, with a decrease for HP.

Conclusions

There is sufficient evidence to demonstrate that EDA and HRV are reliable measures to be combined to increase sensitivity and accuracy for the study and understanding of complex cognitive states, however, there are few investigations that confluence music with deafness and the recording of physiological parameters, so the relevance of our research lies in the conjunction of several elements that have been studied separately or only in hearing people. Although the study presented here is a pilot and exploratory research, and the results are neither conclusive and not generalizable it is essential to make this type of approach to know and adapt the tools and parameters for the study of deep cognitive processes from noninvasive recordings in vulnerable populations

Considerations

Research lines that continue work like ours could focus on exploring whether the design of musical tasks with greater complexity can elicit a greater psychophysiological response in Deaf people or emphasize other sensory stimuli such as vibrotactile stimuli. This could lead to create a simile between sensory modalities and perhaps provoke a physiological response like that generated by auditory stimuli modeled by certain acoustic parameters, such as intensity, tempo, or timbre (Chuen et al., 2016.), modulated by brain reorganization of cortical areas that respond to somatosensory stimuli (Good et al, 2014; Auer et al., 2007), and perhaps this is reflected in increased attentional resources recorded from SCL. Regarding SMS our results showed that although there seems to be no difference in the score between the DP and HP, perhaps if the sensorimotor assessment is adjusted and fine-tuned to measure the occurrence between the stimulus and the action, there may be differences between the consecutive movements between one note and another, although further research is required in this regard. Finally, it is recommended that interdisciplinary working groups be formed to address complex issues such as the one presented in this research, to extend the dialogue and the application of knowledge for vulnerable populations.

References

Auer Jr, E. T., Bernstein, L. E., Sungkarat, W., & Singh, M. (2007). Vibrotactile activation of the auditory cortices in deaf versus hearing adults. Neuroreport, 18(7), 645. DOI: 10.1097/WNR.0b013e3280d943b9

Chuen, L., Sears, D., & McAdams, S. (2016). Psychophysiological responses to auditory change. Psychophysiology, 53(6), 891-904. DOI: 10.1111/psyp.12633.

Da Silva, H. P., Guerreiro, J., Lourenço, A., Fred, A. L., & Martins, R. (2014, January). BITalino: A novel hardware framework for physiological computing. In PhyCS (pp. 246-253)

Dawson, ME, et al (2001) The Electrodermal System. In J. T. Cacioppo, L. G. Tassinary, and G.B. Bernston, (Eds) Handbook of Psychophysiology (2nd Ed), 200–223. Cambridge Press, Cambridge.

Good, A., Reed, M. J., & Russo, F. A. (2014). Compensatory plasticity in the deaf brain: Effects on perception of music. Brain sciences, 4(4), 560-574. DOI: 10.3390/brainsci4040560

Hébert, S., Béland, R., Dionne-Fournelle, O., Crête, M., & Lupien, S. J. (2005). Physiological stress response to video-game playing: the contribution of built-in music. Life sciences, 76(20), 2371-2380. DOI: 10.1016/j.lfs.2004.11.011

Iversen, J. R., Patel, A. D., Nicodemus, B., & Emmorey, K. (2015). Synchronization to auditory and visual rhythms in hearing and deaf individuals. Cognition, 134, 232-244. DOI: 10.1016/j.cognition.2014.10.018

Markopoulos, P., Read, J. C., MacFarlane, S., & Hoysniemi, J. (2008). Evaluating children's interactive products: principles and practices for interaction designers. Elsevier.

Patel, A. D., & Iversen, J. R. (2014). The evolutionary neuroscience of musical beat perception: the Action Simulation for Auditory Prediction (ASAP) hypothesis. Frontiers in systems neuroscience, 8, 57. DOI: 10.3389/fnsys.2014.00057

Posada-Quintero, H. F., Bolkhovsky, J. B., Qin, M., & Chon, K. H. (2018). Human performance deterioration due to prolonged wakefulness can be accurately detected using time-varying spectral analysis of electrodermal activity. Human Factors, 60(7), 1035-1047

Posada-Quintero, H. F., & Chon, K. H. (2020). Innovations in electrodermal activity data collection and signal processing: A systematic review. Sensors, 20(2), 479. DOI: 10.3390/s20020479

Sokhadze, E. M. (2007). Effects of music on the recovery of autonomic and electrocortical activity after stress induced by aversive visual stimuli. Applied psychophysiology and biofeedback, 32(1), 31-50. DOI: 10.1007/s10484-007-9033-y

Van Der Steen, M. C., & Keller, P. E. (2013). The ADaptation and Anticipation Model (ADAM) of sensorimotor synchronization. Frontiers in human neuroscience, 7, 253. DOI: 10.3389/fnhum.2013.00253

Notas Biográficas

Miguel Alberto Martínez Luna is a graduate of Biomedical Systems Engineering at UNAM. He has worked professionally at the National Institute of Rehabilitation (INR) and the National Institute of Cardiology (INC).

Fernando Uristy Osornio García is a graduate of Biomedical Systems Engineering at UNAM. He currently works as a researcher and consultant in the area of user experience design.

Dra. Coral Italú Guerrero-Arenas is a Ph.D. in Musical Cognition and a postdoctoral researcher in the Department of Biomedical Systems of the Faculty of Engineering at UNAM. Is a member of the National System of Researchers level C, CONACyT, and her line of research is in reference to cognitive processes in vulnerable populations. https://orcid.org/0000-0003-3253-6574

Dr. Guillermo Hernández-Santana is a Ph.D. in Anthropology, and Professor of linguistics at the ENAH (National School of Anthropology and History), and a member of the Academy of Mexican Sign Language. His work is about the grammatical study of LSM. https://orcid.org/0000-0003-0367-357X

Dr. Leonardo Borne is a Ph.D. in Music. He researches educational-musical processes in different contexts and the training of musicians and educators. He has several publications in national and international journals and events. https://orcid.org/0000-0002-8843-7017

Dr. Luis Jiménez-Angeles is a Full-Time Associate Professor C in the Department of Biomedical Systems Engineering of the Faculty of Engineering at UNAM. Is a member of the National System of Researchers Level 1, CONACyT, and an active member of the IEEE Engineering in Medicine and Biological Society and the Mexican Society of Biomedical Engineering. https://orcid.org/0000-0002-7390-0814