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Sensing the Music: An Audiovisual Environment for ASD Therapy

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Abstract. This paper presents the effects of a designed combination of music and color ambience lighting on symptoms of Autism Spectrum Disorder (ASD) with focus on childhood Alexithymia II, through exposure to a non-invasive audiovisual environment with minimal engagement of parents and medical staff. The proposed audiovisual design aims to further enhance the non-verbal communication of the emotions contained in music through the use of color ambience lighting which dynamically changes according to musical harmonies. The novel tone-color mapping principle was created and technically realized with a program application which communicates the structural analysis of music to the Philips HUE® lighting. Effects of the audiovisual musical experience on cortical activity were assessed in an electroencephalography (EEG) pilot study, and significant effects were observed in cortical areas related to semantic processing and theory of mind. Due to relevance of these regions for the proposed application of the audiovisual environment in therapy for ASD children with Alexithymia II, it is suggested that further experimental work is carried out in order to test its effectiveness in treating Alexithymia as a negative factor in social interactions of individuals with ASD.

Keywords. Autism Spectrum Disorder, EEG, Music, Ambience Lighting, Alexithymia II, BA 44

1. Introduction

Autism Spectrum Disorder (ASD) is widely spread among children, and the importance of early intervention is frequently being pointed at, along with considerations for parental stress [1] [2]. Among other characteristic features of ASD which may negatively affect social interaction are atypical neural self-representation [3], impaired mirror-neuronal activity [4], impaired facial recognition [5], and Alexithymia II as a common disorder related to inability of emotional expression [6], and correlated with empathy deficits [7].

In order to provide a sensory relief for ASD symptoms, multisensory Snoezelen® rooms may be built into healthcare facilities, though with high costs [8], while self-use tools at home may be distributed to the parents of ASD children, however requiring a high variety of tools and parental engagement [9].

Being a mean of communicating and synchronizing emotions among people [6], and evoking processes of emotional contagion and empathy [10], music is appealing to ASD individuals [11] [12], and is widely used in ASD therapy [13], among other disorders targeting Alexithymia II [14].

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In this paper proposed is a concept of an audiovisual ambience which utilizes the beneficial sensory and cognitive properties of stimulation with music and color ambience lighting in treatment of ASD symptoms, while reducing the engagement of parents and caregivers. In further sections presented are the main features of the lighting-music ambience (Section 2), its physiological effects as demonstrated in a pilot EEG study on healthy subjects (Section 3), and indications for application in music therapy for ASD children (Section 4), followed by the conclusions (Section 5).

2. Music-Color mapping features and technical realization

A characteristic feature of the long history of color-music concepts [15] has been their diversity in terms of mapping, and to the author's knowledge there has so far been no color-based lighting music visualization which would adhere to variability in color-music preferences. In this section proposed is a color-music mapping concept providing an element of adaptability in tone-color correlations, based on the principle of transposability from music theory [16], and utilizing a program for communication of the mapping to ambient LED lighting Philips HUE®.

The audiovisual design refers to a suggested analogue between the two main degrees of musical tonality whose subjunction defines a tonality through a cadence (i.e. tonic and dominant), and pairs of the complementary colors in the spectrum. The rest of the tonal degrees are assigned one of the main functions according to music theory, and are therefore translated into the spectrum according to the distance from the colors of the dominant and tonic (Figure 1).

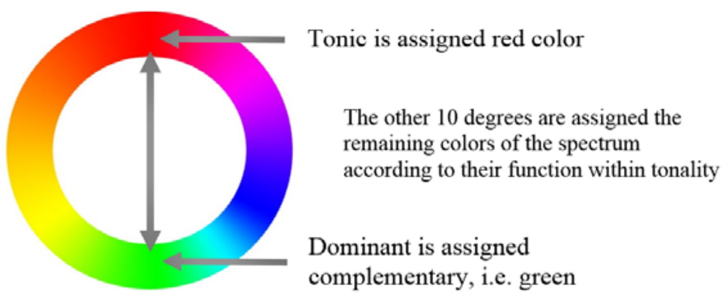

Figure 1. An example of the principle of the used mapping scheme, shown on a color spectrum.

The program created to match the tonalities of music to the colors of lamps utilizes an external MP3 music file and a list of timings corresponding to harmonic changes in music, matched with a list of colors selected for visualization of a piece. The first number in the "timings" file represents the moment in time in which the light color should change into the first color appearing in the "color" list, which contains the indexed RGB color combinations. The program then reads the first line of the "color file", initializes the color, and starts the music, interpreting the rest of the file's lines in a loop. In each iteration, a line of both files is read, and a pause which is defined by difference between the current and previous timing is made between "change color" commands, which are sent to the lamps via Wi-Fi. As a result, colors of ambience lighting dynamically change throughout the musical piece, creating an audiovisual ambience (Figure 2).

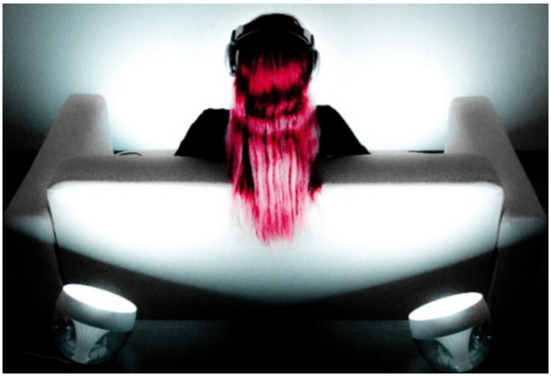

Figure 2. Photo showing the audiovisual environment in which a subject listens to music visualized by the program which communicates with Philips HUE Iris ambience color lighting.

3. Neurophysiological effects of the proposed audiovisual stimulation

Effects of an audiovisual stimulation which is based on a combination of music and color ambience lighting have not been examined so far to the author's best knowledge, in spite of a wide examination of the effects of music on cognition in studies utilizing techniques for collecting physiological data, e.g. electroencephalography (EEG), functional magnetic resonance imaging (fMRI), or positron emission tomography (PET) [17].

For the purpose of testing a hypothesis on effectivity of exposure to the designed audiovisual ambience on semantic processing of music, a study was conducted using EEG measurements of electrical cortical activity. As explained further in this section, the results showed significant effects of the audiovisual vs. audial-only condition on the electrical neuronal activity related to verbal and musical semantic processing, and to several features related to social impairments in ASD.

3.1 Materials and Methods

In this section presented are the audial and visual stimuli which were used during the experimental study, as well as the subjects, setup, and the EEG equipment used for the measurements.

Six healthy subjects, three female and three male of average 27 years of age and with various nationalities gave an informed consent for a voluntary participation in the pilot study, performed under supervision of a neuroengineering expert. A controlled, noise-free laboratory environment was covered entirely with white cloth and equipped with four Philips HUE® Iris wall-wash lamps placed laterally in the eye level of participants who were seated in an armchair in the center of the room, in order to provide visibility of the lighting stimuli, and a stereo effect of the audial music stimuli. Experimenters were seated at a control table with working equipment, set behind the subjects in order to avoid possible distractions.

Stages of the experimental protocol (Figure 3) consisted of baseline (BL) condition, i.e. dark and quiet ambience with no audiovisual stimuli, audial (M) condition applying two pieces of classical music, and audiovisual (L&M) condition applying additional dynamic color ambient lighting according to the mapping system presented in Section 2.

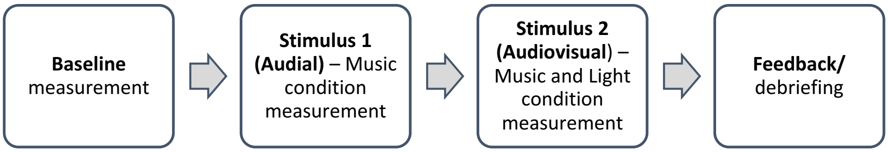

Figure 3: Scheme of experimental protocol

3.2 Signal acquisition and analysis

A standard Waveguard™ electrode cap with 32 positions was used for EEG measurements. Each signal was first preprocessed in the Asalab™ software by being subsequently passed through a 50Hz notch filter and a band pass filter with cut-off frequencies of .5Hz and 45Hz. Next, the filtered data was read into a dedicated Matlab® script. In cases of a broken lead or other hardware problems, the data was excluded from further analysis. Segments of 2 seconds were analyzed according to the following procedure. First, the amplitude threshold detection (max-min difference>100 μV) was applied to identify artefacts. When an artefact was detected in one or more channels, the entire 2-second epoch for all channels was excluded from further analysis and the analysis proceeded to a new period, starting 0.5 seconds later. This procedure was repeated until the first next artefact-free 2-second segment in all channels was identified. The analysis proceeded with the next non-overlapping 2-second segment. The analysis of each approved 2-second EEG segment was split up in time-domain and frequency-domain analysis: basic time-domain characteristics (within-segment min-max amplitude, standard deviation, minimum-maximum slopes, and standard deviation of slopes) were calculated, time-stamped, and stored in the database of EEG features for each of the valid EEG channels. Frequency (spectral) analysis was applied to determine per-channel absolute and relative (to total power) energy in the classical frequency bands: delta (.5-3.5 Hz), theta (4-7.5 Hz), alpha (8-14.5Hz), SMR (12.5-15.5), beta (15.5-29.5Hz) and gamma (30-45Hz); which were time-stamped and stored. The next step was selecting a fixed number of non-overlapping 2-second segments for each condition that was used for calculating within-condition, per-channel statistics. The resulting within-channel statistics were further condensed into EEG characteristics that were averaged across various regions. Finally, statistical tests were carried out for determining statistical differences between and within all the conditions.

3.3 Results and discussion

Statistically significant differences ($p<0.05$) were found and validated between all pairs of conditions, in a host of EEG parameters in right and left frontal and temporal cortical areas. The neural modulation of the electric cortical activity was higher in the audiovisual condition (L&M) than in the audial-only music condition (M) (Figure 4).

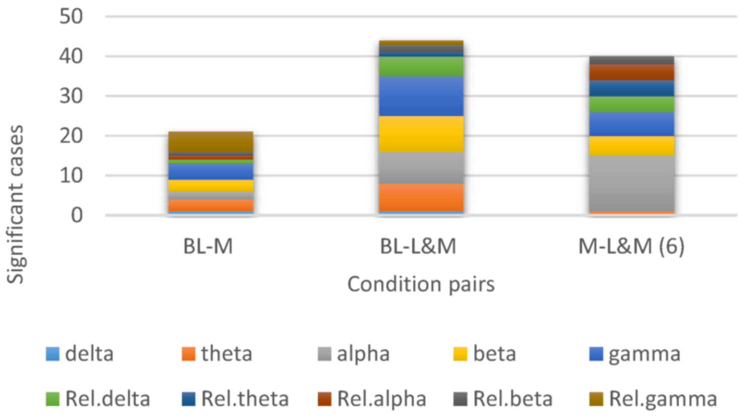

Figure 4: Significant cases of modulation in frequency bands are presented according to condition pairs. The highest amounts of cases is observed in BL-L&M and M-L&M condition pairs. In M-L&M condition pair, alpha power was the frequency band which was significantly alternated in the highest number of cases.

In order to compare the difference between effectivity of audial-only and audiovisual modes of experiencing music, the statistically significant results in M-L&M condition pair were interpreted within the scope of currently known functions of cortical regions and frequency bands which are due to their typical impairment in ASD relevant to the hypothesis on therapeutic application of the audiovisual environment. Further referenced with relevance to this context are the functions of frequency bands, and Brodmann areas (BA) above which significant differences in electrical cortical activity were found upon comparison of M and L&M conditions (Figure 5).

Delta power increased above BA 40, 42, 44, and 47, whereas theta wave was significantly modulated above BA 5, 7, 8, and 44. Most importantly, a widespread significant decrease of alpha wave in L&M relative to M condition was measured above BA 1, 2, 6, 8, 37, 39, 40, 44, 45, and 47, which was related with previously reported increase in alertness, and the active information processing of words' meaning [18]. Significant cases in which alpha wave oscillations coincided with theta wave oscillations are interpreted in relation to the internal mental top-down processing, and a good cognitive and memory performance [19]. Beta power significantly decreased above BA 6, 42, 44, 45, 47L, which is in line with the reported role of lower frequencies oscillations in top-down processing [20], conveying top-down predictions of content to lower-level regions [21], construction and representation of sentence-level meaning and top-down predictions about upcoming linguistic input [22], and synchronization across sensorimotor cortical networks [6] [9] [10]. Gamma wave, associated with feature integration, stimulus selection, attention, multisensory, and sensorimotor integration [21], was found to oscillate above BA 2, 6, 18, 40, and 44.

BA 44, 45, and 47 have previously been related with comprehension of affective prosody and expressional qualities of music [23]. BA 44 and 45 have been associated with processing of pleasant music [24], with word retrieval along with BA 18 and 37 [25], and with generating both sentences and melodic phrases along with BA 6 [26]. BA 8 and 39 have been reported to generate sentences only [26], although our results suggest their additional role in processing musical phrases. BA 18, 37, 44, and 45 have been related with both words and face encoding [27], and BA 5 with verbal processing and imagery [28]. BA 18, 37, and 47 were related with attribution of intentions to others [29], whereas BA 6, 40, and 44 were related to social perception, with BA 40 being additionally related to self-other overlap within social perception and empathy [30]. BA 40 has also been related with semantic processing of visual word representations, along with BA 45 and 47 [31], and with verbal creativity along with BA 39 [32], which was also related to theory of mind [33], whereas BA 1 and 2 were associated with mirror neuron activity [34].

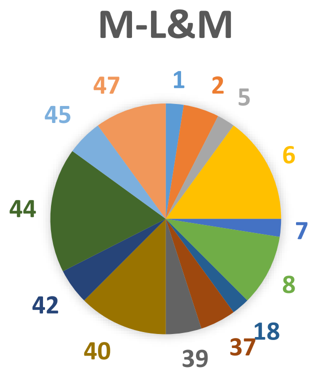

Figure 5. Cases of significant changes between the condition pairs, presented proportionally according to Brodmann areas (BA). BA 44, i.e. opercular part of Broca's area with a function in semantic processing is the location in which the highest percentage of significant cases was measured, due to L&M condition

4. Future work. Implications for application in ASD therapy

In this section a concept of application of the audiovisual musical environment is proposed for therapy with childhood ASD. Based on findings of the EEG study on significant neuromodulation in the context of semantic processing, memory, theory of mind, social perception, and empathy, the therapy targets primarily Alexithymia II, as a disorder of verbal expression of emotions which further negatively affects social interactions. Other envisioned outcomes include anxiety-relief for the ASD children and reduced engagement of parents and caregivers in therapy as the proposed activity is based on beneficial effects of the multisensory stimulation that does not require any guidance by third parties.

4.1 Application of the designed audiovisual music therapy in free-play recreational therapy for ASD children

The proposed music therapy is envisioned to take place in an audiovisual enriched environment for children's free-play activities. Cycles of classical music pieces inspired by childhood themes and fairy tales are proposed as audial stimuli. Having specific titles indicating semantic content of music, the pieces may facilitate imagining and memorizing the story and character of the music and its associated emotions by non-verbal means, i.e. through music and lights, which is presumably suitable for ASD children with difficulties in verbal communication.

The choice of music is based upon the following selection criteria. Due to the reported preference of ASD children for the classical music genre [35], and their intact capability of processing musical emotion [11] and accurately associating musical feelings with representations of emotions [36], the selected cycles of classical music pieces are rich in variety of semantic/emotional content and consist of multiple, short pieces with a high variety of emotional states with a main theme and suggestive titles, e.g. Saint-Saens' "Carnival of animals" with a theme song for every animal, Prokofiev's "Peter and the Wolf" with theme music for every character, Debussy's "Children's corner" with a childhood-themed title for each song, Tchaikovsky's "Nutcracker" suite with different theme dances (e.g. 'March', 'Dance of the sugar plum fairy', 'Chinese dance' etc.). The indications of semantic/emotional content of each selected song allows a liberty of its individual imaginative interpretation, meaning that every child can experience the music in their own, unique way [37], which can become a personal memory and an association with a given emotion [10].

4.2 Estimated outcomes of the design application in ASD therapy

An improvement in ASD children's impaired identification of emotions due to Alexithymia II is estimated to result from a periodical exposure to the audiovisual experience of the selected music [38], with a limited use of words which are only necessary for labeling and suggesting semantic content of music.

Since music listening involves introspection [39], social interaction [40], and in case of ASD children, a preserved sense of empathy [41], it is suggested due to results of the reported EEG study that a positive impact of music on ASD children may be further enhanced when music is experienced in the proposed audiovisual mode, in terms of understanding, expressing, and memorizing of emotions expressed in music, and attribution of emotions to others and self-other relation as important factors of social interaction. In line with the theory of cognitive mapping as a memorizing technique [42], it is estimated that the application of color ambience lighting in visualizing music may facilitate creating a cognitive map of musical content, i.e. an enhanced "external memory extension" on a multisensory audiovisual level, and consequently enhance memory of music and the associated emotions.

5. Conclusions

In order to address impaired social relations with ASD children with minimized engagement of parents and caregivers, a concept of audiovisual music-and-light based therapeutic ambience is proposed for application in therapy for Alexithymia II in childhood ASD. Following results of EEG pilot study, in which significant effects of the audiovisual stimuli on subjects' cortical activity related to semantic processing and social cognition were measured, it is implied that additional studies employing the proposed audiovisual stimuli should be carried out in order to further examine the effects of such audiovisual ambience on healthy and ASD subjects, since the affected cortical regions are relevant to the common neurological dysfunctions in ASD.

Based on features of the proposed audiovisual ambience in the context of state-of-the-art research in neural basis of music cognition and childhood ASD, it is hypothesized that a periodical exposure to it may facilitate the process of emotional learning with long-term benefits for social interactions of ASD children.

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