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# An oximetry-based method for monitoring reactions of autistic subjects under music auditions

## *Metodologia baseada em oximetria para monitoramento das reações de sujeitos autistas em audições musicais*

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**Abstract**

This work aims to create a methodology to analyse the physiological effects of people exposed to sounds, specifically music and its elements, using techniques of data acquisition and signal processing to provide objective information on the subjects' reactions, in order to help the use of music in music therapy for autistics. We used a pulse oximeter with data transmission capability, data acquisition and signal processing software. The subjects and/or groups were exposed to several types of music, varying its elements, and the physiologic measurement signals were made. The acquired information data base was then converted into graphics representative of heart rate and arterial hemoglobin saturation. During the measurements, the subjects' behaviour has been observed to relate subjective and objective results. Two groups of subjects (six non autistics and six autistics with diagnosis established) participated on this research, with ages ranging from 7 to 24 years old. As the majority of autistics are male, only boys have been invited to participate of this study. An observation protocol based on autistics behaviour was developed, the vital signals and the subjects reactions were observed and recorded. The results allow to identify and establish in an objective way any influence of music in human behaviour through sound stimulation and vital signals monitoring: $SpO_2$ and HR.

**Keywords:** Blood oxygen saturation, Heart rate, Vital signals measurement.

***Resumo***

*O objetivo deste trabalho foi criar uma metodologia que possibilite analisar os efeitos fisiológicos produzidos pela exposição de pessoas à música e seus elementos, utilizando princípios de detecção, aquisição de dados e processamento de sinais, obtendo-se informações objetivas sobre as reações dos sujeitos, para dar subsídios ao emprego da música na musicoterapia com autistas. Foram utilizados um oxímetro de pulso com capacidade de transmissão de dados e aplicativos para aquisição de dados e processamento dos sinais. Foram realizados experimentos com a exposição dos sujeitos a vários tipos de músicas, com a variação de seus elementos, criando-se, assim, um banco de dados com as medições realizadas, a seguir transformando essa informação em gráficos representativos da evolução dos sinais de FC e de* $SpO_2$*. Durante as medições, o comportamento dos sujeitos foi observado para que o resultado da análise subjetiva fosse relacionado com as medições objetivas. Os sujeitos desta pesquisa encontram-se na faixa etária entre 7 e 24 anos, sendo que a amostra estabelecida foi composta por seis indivíduos não autistas e seis indivíduos com diagnóstico de autismo estabelecido. Como o maior percentual de autistas é do sexo masculino, apenas de sujeitos do sexo masculino participaram. Foi desenvolvido um protocolo de observação baseado no comportamento de autistas, e os sinais vitais foram adquiridos e processados. Como resultado, foi identificada de forma objetiva a influência da música no comportamento humano pelo monitoramento dos estímulos sonoros e dos sinais vitais de* $SpO_2$ *e FC.*

***Palavras-chave:*** *Saturação da hemoglobina do sangue por oxigênio, Frequência cardíaca, Medição de sinais vitais.*

## Introduction

Pulse oximetry is the measurement of the per cent saturation of oxygen in hemoglobin. This measurement is directly correlated to the partial pressure of oxygen in hemoglobin ($pO_2$), which determines how well oxygen is delivered to the body cells. If oxygen is not delivery properly, cells and tissues will be damaged. Oxygen saturation percentage is also a way of identifying how well oxygen is delivered to the body cells (Rusch *et al.*, 1996).

Pulse oximetry has been in use as a medical diagnostic technique since its invention in the early 1970 s. This non-invasive technology is used to reliably assess two key metrics on patients' health: heart rate (HR) and blood oxygen saturation ($SpO_2$) (Shnayder *et al.*, 2005; Tremper and Barker, 1989).

The principle of pulse oximetry is based on the red and infrared light absorption characteristics of oxygenated hemoglobin or oxyhemoglobin ($O_2Hb$), and deoxygenated or reduced hemoglobin (Hb). Oxygenated hemoglobin absorbs more infrared light and allows more red lights to pass through. In other hand, deoxygenated hemoglobin absorbs more red lights and allows infrared light to pass through. At the measuring site there are constant light absorbers always present, such as skin, tissue, venous blood, and the arterial blood (Bos *et al.*, 1990; Pologe, 1987; Smiths, 2008; Solaris, 2008; Tremper and Barker, 1986).

However, with each heart beat, there is a surge of arterial blood, which momentarily increases arterial blood volume across the measuring site. This results in more light absorption during the surge. If light signals received at the photo detector are looked at 'as a waveform', there should be peaks at each heartbeat and valleys between heartbeats. If the light absorption at the valley (which should include all the constant absorbers) is subtracted from the light absorption at the peak then, in theory, the result is the absorption characteristics due to added arterial volume of blood only. Since peaks occur with each heartbeat or pulse, the term "pulse oximetry" was coined. This solved many problems inherent to oximetry calibration in the past and is the method used today in conventional pulse oximetry (Bos *et al.*, 1990; Pologe, 1987; Smiths, 2008; Solaris, 2008; Tremper and Barker, 1986).

Pulse oximetry measurement involves the projection of red and near-infrared light (typically 650 and 805 nm) through blood vessels near the skin. Pulse oximeters usually incorporate a plastic housing that slips over the index finger or earlobe. The housing contains an array of LEDs along one inner surface and an optoelectronic sensor opposite (Bos *et al.*, 1990; Pologe, 1987; Smiths, 2008; Solaris, 2008; Tremper and Barker, 1986). By detecting the amount of light absorbed by hemoglobin in the blood at those two wavelengths, the level of oxygen saturation can be calculated. In addition, heart rate can be determined from the pattern of light absorption over time, since blood vessels contract and expand with the patient's pulse (Rusch *et al.*, 1996; Shnayder *et al.*, 2005). Figure 1 shows a general pulse oximeter circuit diagram.

Clinical application of $SpO_2$ includes anaesthesia, intensive care, neonatal care, newborn nursery, critical transport, exercise lab, sleep lab, home care patients, other patient conditions, blood flow assessment, cardiopulmonary arrest, among others.

In pulse oximetry measurements accuracy and normal values are adopted. Accuracy depends directly of the measurement range. A range from 0 to 49% implies in 'no definition' for accuracy, from 50% to 79% is related to accuracy of ± 3%, and from 80% to 100%, it has ± 2% of accuracy. A normal value of $SpO_2$ is between 96 and 98% for a healthy adult in normal conditions, but the normal value is different for other status, such as age, altitude, heavy smoking, etc.

In a traditional methodology to apply DSP in pulse oximetry, there are three steps in analysis of alternate transforms which would be considered: the FFT optimisation, the FFT (Fast Fourier Transform) and DCT (Discrete Cosine Transform) processing results, and the post processing analysis. The optimisation analysis is performed on the FFT by fixing all the variables except one, and is calculated the FFT for that range. The FFT analysis is used to select a more optimum

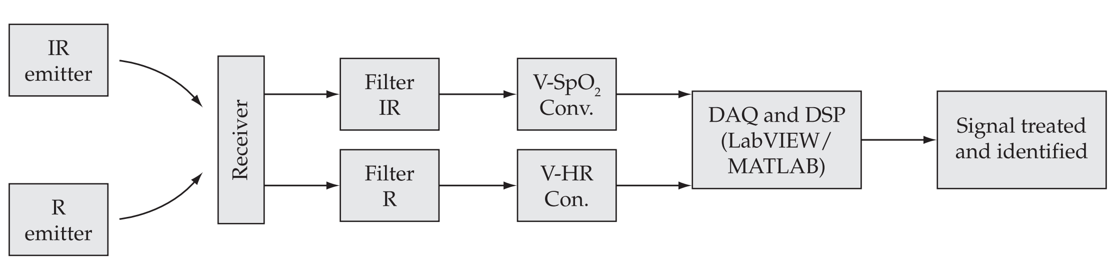


**Figure 1.** General pulse oximeter circuit diagram.

range of transforms for further analysis of the FFT and DCT (Bores, 2008; Rusch *et al.*, 1996).

The difference between music in medicine and music therapy in medicine is an issue of several theoretical studies of contemporary music therapy (DiLeo, 1999). In the introduction of her book on the subject, Dr. Cheryl DiLeo argues that music in medicine is composed of experiments in which the patient is primarily exposed to hear pre-recorded music, not selected by therapists such as doctors, nurses, dentists or other health care professionals, using specialized equipment. Still the author referred to music therapy in medicine as an approach to medical patients, which always involves a therapeutic process, a music therapist and a therapeutic relationship, which is established through music and the process and where various musical experiences are used, such as improvisation, re-creation, composition, and also listening to music, mostly performed by the therapist (DiLeo, 1999).

Studies focusing the effects of music therapy on the health of individuals with emotional and behavioural disorders, especially autistics, have presented good results (Accordino *et al.*, 2007; Sausser and Waller, 2006; Trevarthen, 2005), but they are still very few.

The purpose for this study is to develop a methodology based on pulse oximetry that provides an objective data to help in monitoring of autistic subjects' therapy progress, complementary to the subjective methods based on the therapist expertise.

## Material and Methods

The music session is formed with six parts: without music before, mix music, childish music, classic music of fire, classic music of water, and without music after. This nomenclature for moments in music session was adopted according to Bush (1995). Each session took about 40 minutes, while the effective time for measurements was from 25 to 30 minutes. A previous measurement was taken to make reference values for each subject before start music sessions and took 2 minutes.

Mix music is formed with different sounds to stimulate antagonistic reactions into the same period. Sounds such as motorcycle and cellphone ring are inserted in this moment and took 3 minutes and 32 seconds. This moment had following composition through its period: "Toccata and Fugue" in background with dentist engine and cellphone ring in foreground; "Junina's music" with helicopter and motorcycle; "Toccata and Fugue" with cellphone ring, siren, and motorcycle; cellphone ring and motorcycle; siren and motorcycle; and "Toccata and Fugue" with dentist engine.

Childish music is formed with popular songs from childhood age and took 4 minutes and 11 seconds. The songs were "Boi da Cara Preta", "O Pato", and "Sapo Cururu".

Classic music of fire is formed with music that evokes strong feelings, such as rage, passion, fights, courage, etc. They have strong sounds and their more pronounced musical parameters are intensity and loudness. This moment took 9 minutes and 10 seconds. The musics used in this moment were "Firebird suite, Berceuse" by Igor Stravinski (with the harmonic orchestration creates a shimmering effect, providing a rich range of images and responses); "Concert for Piano and Orchestra No. 2, *allegro non troppo*" by Johannes Brahms (arouses various emotions, especially strong emotions such as anger, guilt, and longing); "The Planets, Jupiter" by Gustav Holst (strong music, with great variety of sounds); "The Planets, Uranus" by Gustav Holst (strong movements, which evokes responses strongly sentimental); "La Mer" by Claude Debussy (music with three strong movements, seeking strong images); and "Tocatta and Fugue in D Minor" by Johann Sebastian Bach.

Classic music of water is formed with soft sounds that help to develop creative spontaneity and to set free feelings as lost, anxiety, and fear. They have soft sounds and their musical parameters more pronounced are harmony and soft timbres. This moment took 5 minutes 45 seconds. The musics used in this moment were "Music for Chords, Percussion, and Celesta, 1st movement" by Bela Bartok (music with quality to attract deep answers); "Symphony No. 2, 3rd movement, *andante*" by Johannes Brahms (music inspiring and lively, evoking many positive expressions); "Chords Quartet in C Major, opus 131" by Ludwig van Beethoven (soft music, seeking inner peace and youth); "The Planets, Venus" by Gustav Holst (inspired by profound expressions of love and longing); "Tristan und Isolde, Prelude and Death of Isolde" by Richard Wagner (tone poem that explores the erotic and spiritual); "The Engulfed Cathedral" by Claude Debussy (music soft and deep, that evokes a romantic sense of longing).

A final measurement was taken to observe subjects' conditions after the music sessions and took 2 minutes.

The subjects for this study were aged from 7 to 24 years old; six subjects with autistic characteristics, with diagnostic established by a qualified professional were chosen, and six without that condition.

*Rev. Bras. Eng. Biom., v. 25, n. 3, p. 175-184, dez. 2009*
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Only male gender subjects had invited since the majority of autistic population is formed with male subjects.

At least three sessions were done for each autistic subject, but only two sessions were considered for each one because of their rejection to equipment in the beginning of measurements. However, two of these subjects had more rejection to the $SpO_2$ sensor than other ones, then they had only one session completed. The repetition of measurement was also to confirm that their medicine or any previous stress situation did not cause any interference in their behaviour.

Only one session was chosen for each non-autistic subject, because their individual sessions were very similar for each one. This project has been submitted to and approved by an Ethics Committee (CEP/UNITAU nº 144/06).

A pulse oximeter (MedChoice, model MD300I) was used for its data storage and transfer capabilities. This model is based on BCI technology and it is sold with MedView® software for data acquisition through USB port.

MATLAB® (Mathworks) software was used to generate spectrograms for types of music used in music sessions. Also, it was used to plot graphs for individual sessions in order to provide information for therapists' diagnosis and to follow therapy progress.

The system proposed has a great advantage in comparison with similar ones: low cost. It was possible to join a qualified hardware and equally good computational science software to elaborate a reliable and flexible system to support a new methodology to follow therapy progress of autistic subjects based on pulse oximetry. The cost comparison between three similar pulse oximetry systems resulted in:

- Alive Pulse Oximeter (from Alive Technologies): US$ 1,050.00 (software not included);
- BCI 3301 Hand-Held Pulse Oximeter: US$ 1,190.00 (software not included);
- MedChoice MD300I: US$ 575.00 with proprietary software included and also MATLAB Student Version purchase.

## Results and Discussion

Two specific groups were invited to take part in this research: autistic and conventional (non-autistic), where the second group were formed with arts students, such music and theatre. It is important to note that for music students, classic moments were the most relaxing because their familiarity and preference with this sort of music.

Table 1 shows pathology characterization for each autistic subject.

For the subjective analysis, i.e. observation of the subjects' behaviour, the professional was only able to note the significant changes in those who were lesser time under their care, since non-autistic did not show clearly the impact of music on their behaviour.

In the objective analysis proposed, it was possible for the professional to observe the specific moments, i.e. the sounds most striking for both autistic and non-autistic individuals, because their physiological reactions (HR and $SpO_2$) differ from the pattern established for each individual. Table 2 shows remarks on the reactions of autistic subjects to music and sounds.

Figure 2 shows a graph set with music, $SpO_2$, and HR graphs. Figure 3 shows spectrograms for each type of music: mix, childish, classic of fire, and classic of water.

These results are important because of the possible association of a specific moment within a sound and the subjects' reactions when exposed to this. Those reactions are analysed by expert professionals that establish $SpO_2$ and HR patterns for each subject before their exposure to the sound. After that, areas of relaxation and excitement are identified and associated to the correspondent sound moment or period, represented graphically (see Figure 2), to use or discard such passages as a therapeutic procedure, established by a qualified professional.

**Table 1.** Individual characteristics of autistic subjects.

| Id. | Description |
|---|---|
| A.L. | Gender: male; Age: 18 y.o.<br>Date of birth: 07/11/1989<br>Diagnostic conclusion: Autism and X-Fragile |
| B.B. | Gender: male; Age: 9 y.o.<br>Date of birth: 12/06/1998<br>Diagnostic conclusion: Autistic disorder |
| F.A. | Gender: male; Age: 10 y.o.<br>Date of birth: 30/06/1997<br>Diagnostic conclusion: Autistic disorder |
| J.G. | Gender: male; Age: 7 y.o.<br>Date of birth: 25/10/2000<br>Diagnostic conclusion: Childish autism and X-Fragile |
| J.V. | Gender: male; Age: 7 y.o.<br>Date of birth: 19/04/2000<br>Diagnostic conclusion: Childish autism |
| L.C. | Gender: male; Age: 24 y.o.<br>Date of birth: 21/08/1983<br>Diagnostic conclusion: Autism |

**Table 2.** Notes on the behavior of autistic subjects. Remarks on the reactions of autistic subjects to music and sounds.

| Id. | Description |
|---|---|
| A.L. | The sessions were conducted in a calm and quiet way, with great cooperation and participation.<br>The musics that attracted interest and attention were those with faster pace. After all agitation caused by music, listening to a song slower, made him calm and relaxed. Demonstrated fondness for childish music (especially music "O Pato") and the classic music of water. |
| B.B. | The progress of the research was excellent, with great understanding and cooperation of the subject. The sessions were very productive and calm, being held to collect data on the same day and always in an entertaining way. The musics that pleased were childish, with little bounce to the music of fire, and some days was uncomfortable and a little impatient with the mix music, but after this state, to listen to childish music or classic music of water, the impatient behavior decreased, reaching disappear. |
| F.A. | The progress of the research was good, due to the cooperation of the subject, which in most cases did not refuse to perform.<br>It was observed a great interest in childish music, especially with different voices or voices of children and moderate playing, i.e., music a bit wild.<br>In all sessions the classic music of fire was rejected, focusing on stretches with differentiation loudness and timbre. |
| J.G. | The adaptation to the equipment and his hand awareness were difficult, even showing interest. In all initial attempts to sensitize the hand, the subject did not take place the tape or modeling clay or the sensor in his finger, removing them immediately, and being an instant action. Thus, the pace of research has been slower.<br>In the last weeks of work, the subject surprised, because he stayed with the sensor on the finger, showing no rejection, thus allowing the completion of data collection. In all sessions, the observer can see the great interest and pleasure to listen to childish music, and demonstrating attentive and happy to listen to the music of the duck ("O Pato"), remaining more calm and quiet. |
| J.V. | The first data collections were quiet, always showing great satisfaction to hear childish music, especially "O Pato".<br>In some sessions had to start collecting data with childish music, in the case with song "O Pato", because he showed more interest and tranquility, which encouraged him to perform all other measurements. At the end of the study showed relaxed, calm and peaceful. |
| L.C. | The research had great progress, due to the excellent cooperation and participation of the subject.<br>Rejection presented to the music mix due to the sounds of high-speed engine and the motorcycle. Note the great sensitivity to acute sounds. The childish songs did not please him, but was patient and listened to all sessions, always demonstrating willingness and interest.<br>The classic music of water and fire aroused interest and appreciation, making possible to do the research more easily and tranquility due to the state of relaxation. |

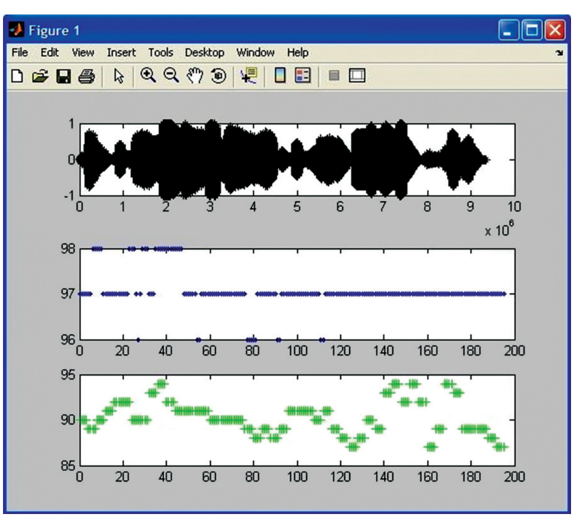


**Figure 2.** Graph set with music, $SpO_2$, and HR. This screen allows to compare signals of music, $SpO_2$, and HR. In this first view, music signal is showed as a graph of p.u. versus sampling.

In the case of autistic subjects, identifying sounds that relax them provides an extra tool to make their interaction easier with outside world. On the other hand, the passages causing repulsion (excitation) should be carefully avoided in future sessions, because they weaken their closeness and interaction with others, and the adaptation to new situations.

Graphics in Figures 4 to 7 make possible to see some subjects' physiological response to stimulation provided through music sessions. Figures 4 and 5 show HR and $SpO_2$ measurements for an autistic subject. Figures 6 and 7 show HR and $SpO_2$ measurements for a non-autistic subject.

The autistic subjects generally tend to have significant changes when something arrives to interact with them, through stimulations into their senses, awaking their interest. The observations (usually subjective) during the music sessions showed that the sounds which produce relaxation are directly correlated with the de-

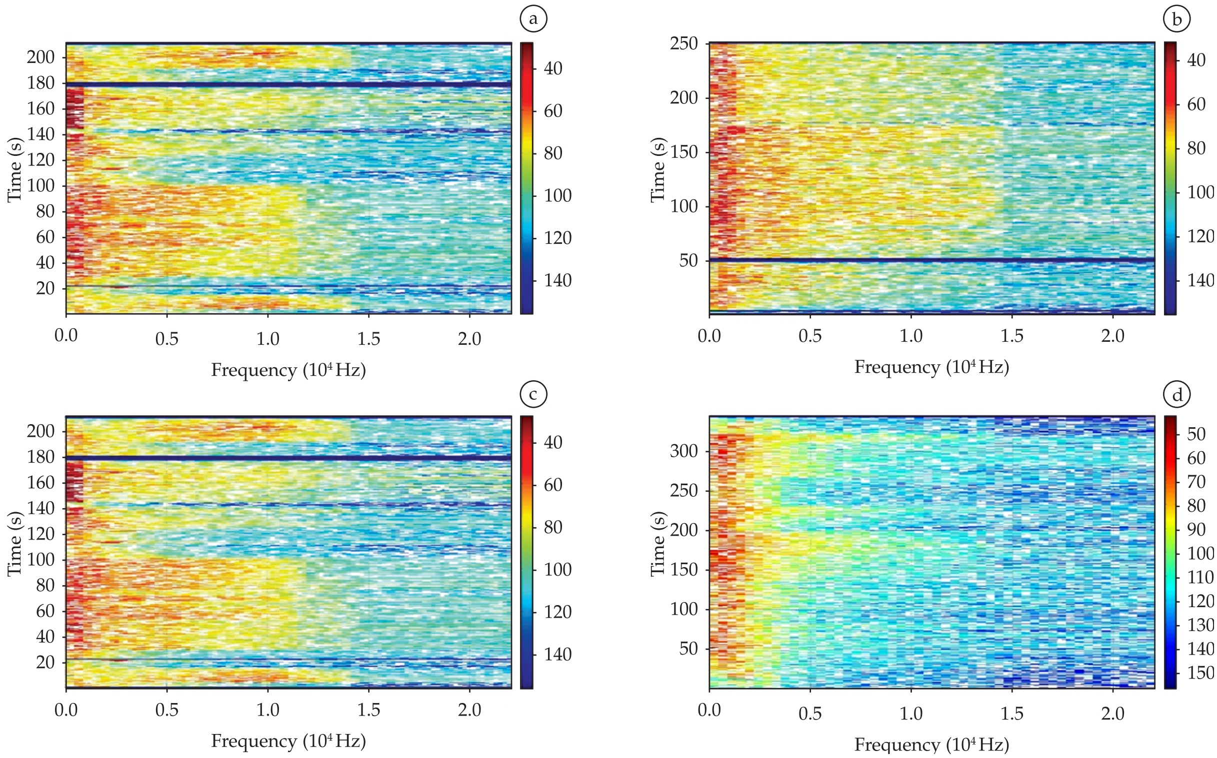


**Figure 3.** Spectrograms, respectively for mix music (a), childish music (b), classic music of fire (c), and classic music of water (d). It is possible to find in these spectrograms how the spectral density of a signal varies with time, observing the intensity of sounds that influence the subjects' behaviour.

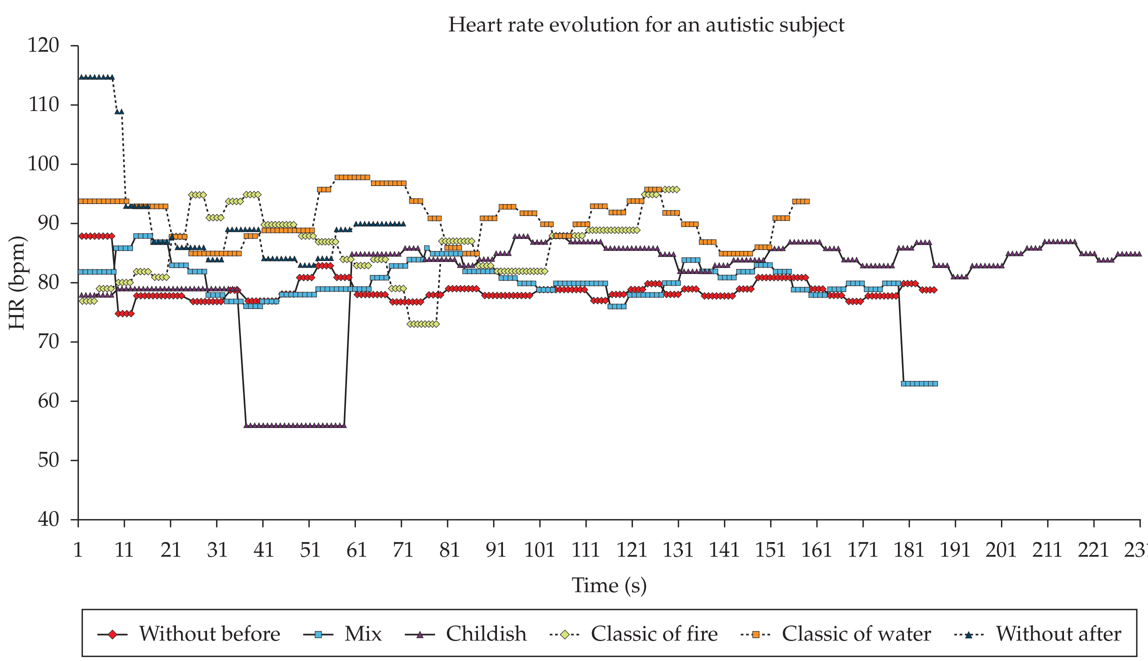


**Figure 4.** Results of HR for an autistic subject. It was established HR value as 79 bpm for this subject. According to therapist orientation, this normal value must have expanded to 75-84 bpm range. It is possible to see that an autistic subject varies his/her heart rate over range in many times for any session, except to childish music session and without music before session. These variations are constant for all autistic subjects, but only the therapists who follow each subject can analyze if these reactions are positive or negative to this one.

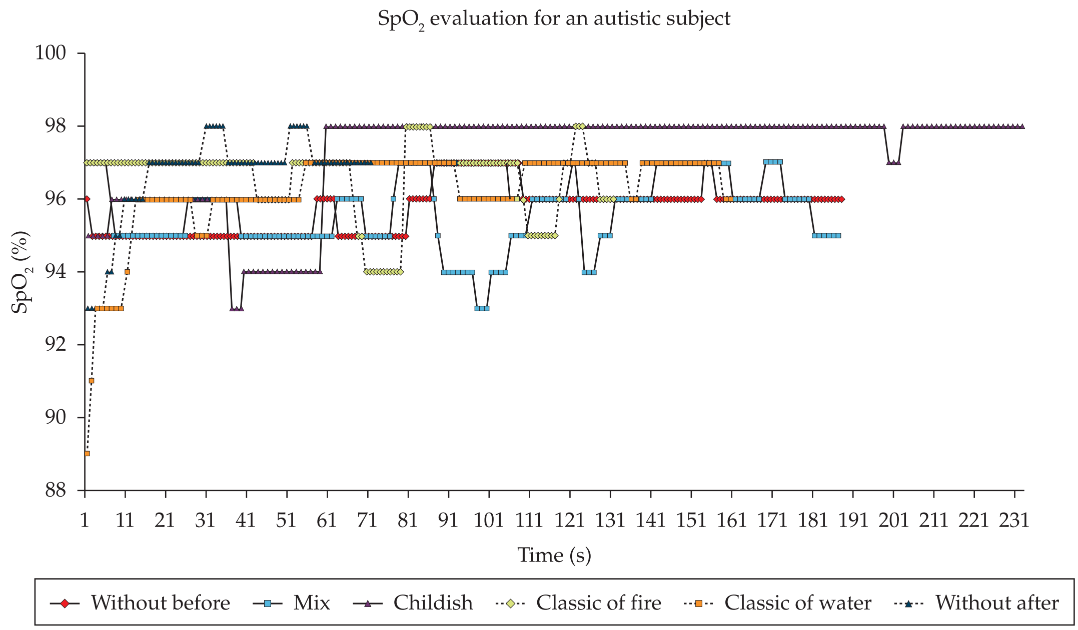


**Figure 5.** Results of $SpO_2$ for an autistic subject. It have been established 96% as $SpO_2$ value rate for this subject. It can be observed the same behaviour in comparison to HR evaluation.

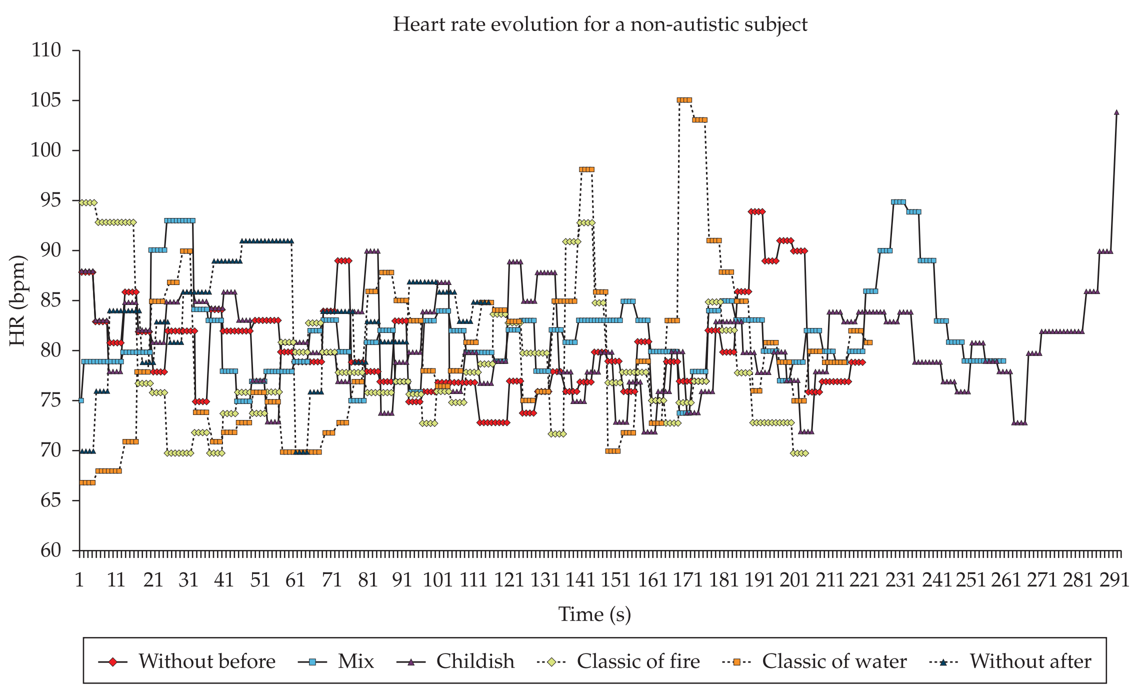


**Figure 6.** Results of HR for a non-autistic subject. Almost all measurement is into the value range established (75-85 bpm for this subject). There are variations, but they are more discrete than an autistic subject's evaluation.

gree of difficulty in social interaction and the type of autism, but for musics that produce agitation, the tolerance may be related to age and treatment time. For non-autistic subjects it was observed that the sounds producing relaxation and excitement are the same regardless the age, given that the subjects participating in the experiment had common living, i.e., they interact in similar environment.

During the objective methodology (measurements of vital signs), it was observed that subjects with autistic disorders and autism only, who participated in this study, had less difficulty in social interaction be-

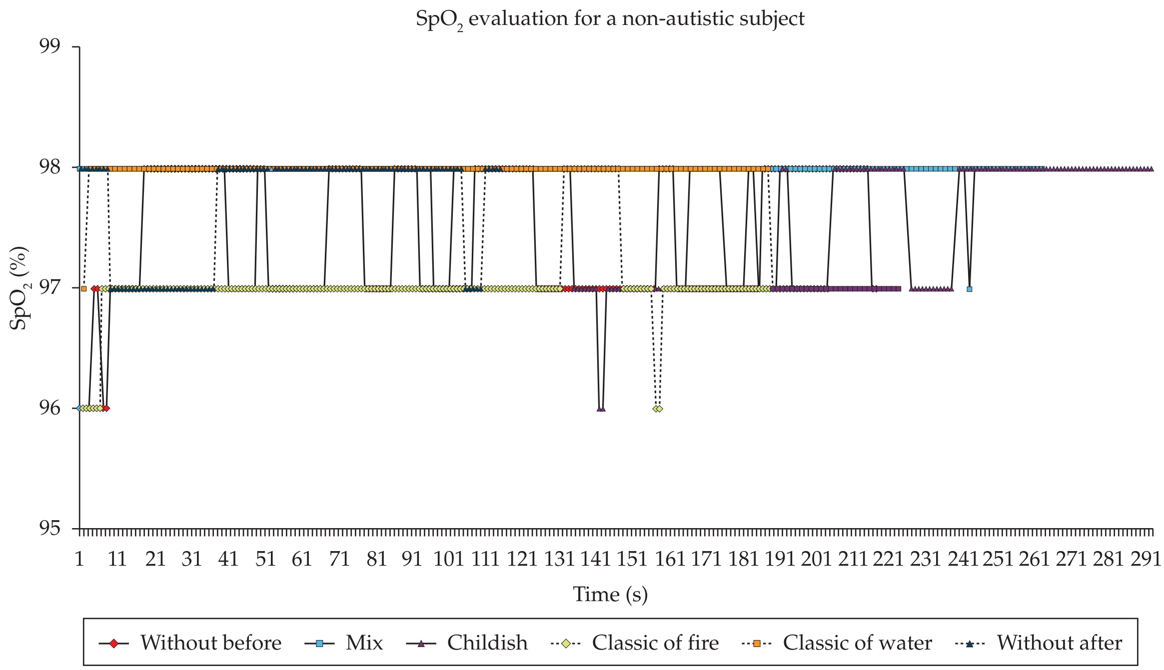


**Figure 7.** Results of $SpO_2$ for a non-autistic subject. For this subject had established 97% as $SpO_2$ value rate. Also only discrete variations can be observed, such as his/her HR evaluation.

cause of the degree and type of their autism and their treatment time. The reactions, as observed by analysis of the measurements, were more relaxation than excitement cases, and it is similar to the non-autistic subjects, and also that the same types of music provides relaxation, as seen in Figures 4 to 7.

For the subjects of this research with childish autism and with autism and X-fragile, physiological reactions show more excitement than relaxing with mix music and classics of fire and water, and only childish music was able to relax them and allow the deceleration of stereotyped movements. It can be observed in Figures 4 and 5 that some values over or under the pre-established ones for HR and $SpO_2$ (individual measurements) highlight specified moments of excitement and relaxation, respectively.

The physiological reactions of the non-autistic subjects to childish music and classic music of fire and water were relaxing, while for the mix music they experienced much agitation and discomfort, i.e., rejection due to changes in timbres, loudness, and rhythms. These behaviours can be observed in Figures 6 and 7. Note that values over and under the pre-established ones are more closed than for the autistics, but it can be viewed easily instead.

Those behaviours are objective (measurable) representation of subjects reactions to the music exposition for either autistics or non-autistics subjects.

Analyzing the physiological reactions, the classic music of fire caused more agitation than relaxation for autistic subjects, while for the non-autistic group that music was relaxing. The greater the social interaction of autistic subject, more likely the results of physiological reactions were closed to those recorded for non-autistic subjects, enabling check which musics, songs, sounds, rhythms, and timbres might trigger the same reactions or different reactions to the two groups of subjects. This allows the therapist to re-evaluate the repertoire of musics to be applied to autistic subjects.

There is a mass of aspects in the behaviour analysis of autistic and non-autistic subjects resulting from the measurement of their vital signs, which is a clear advantage over conventional subjective methodology, what provides the patients (autistic or not) a better quality of life associated with objective analysis of their progress.

Traditionally, there are several studies and treatment techniques developed for autistic subjects based on the observation of their behaviour. One of those is the 'Applied Behaviour Analysis (ABA)', described as an effective behavioural treatment programme widely used with autistic children to improve socially significant behaviours (Keenan *et al.*, 2005). This technique is consolidated in works such as Sturmey and Fitzer (2006) and Reeve *et al.* (2007), detaching its features, evaluation, efficacy, etc.

Several works have described studies on measurement techniques adopted by analysis behaviour. Fields (1985) studied probe responses and acquisition under stimulus control by the method of stimulus fading. Lattal (2004) studied the cumulative recorder, the most widely used measurement instrument in the experimental analysis of behaviour.

Mathematical analysis had also been privileged to make possible a better comprehension of data spreadsheet and its graphics, images processing, and data acquisition and signal processing. Davison and Charman (1986) studied a methodology for stimulation reinforcement schedule based on a modified multiple-schedule procedure. Myerson *et al.* (2001) described a novel approach to the measurement of discounting based on calculating the area under the empirical discounting function. Shahan (2002) studied the observing behaviour based on reinforcement rate method, varying the time scheduling and appointing results measured. Kessel (2004) studied the use of a Wiener filter estimate for the linear transfer function as improvement for the description of behavioural dynamics.

These characteristics should be associated with the low acquisition cost of equipment, easy access, configuration and use. In addition, the equipment adds other features such as reliability, flexibility, and cost-effective operation and maintenance, since it does not require highly skilled professionals, unlike most of the specialized systems used for similar measurements, such as Alive Pulse Oximeter and BCI 3301 mentioned before, and also equipments used for feedback therapy that includes ECG and EEG.

## Conclusions

Subjects' reactions to music sessions are analyzed through a subjective mode, based on therapist's expertise and ability to observe and to identify changes that occurred. This is often not easy, especially with autistic subjects, which have a strong difficulty to interact with outside world.

The methodology proposed allows a detailed and objective analysis of subjects' reactions, independently of the interaction degree between subject and therapist. Minimal variations in therapy progress can be easily identified, maintaining a record of this progress, identifying what sounds stimulate more a determined reaction, etc.

This methodology is useful not only to subjects identified with pervasive developmental disorders (WHO, 2008), but it can be expanded to patients in a coma or with any level of brain paralysis. More generally, technology may be used to observe reactions of a great sort of patients whose quality of life could be improved and help therapists to have objective data for treatment orientation and, consequently, their therapy accomplishment.

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