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Musical instruments for the measurement of autism sensory disorders

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Abstract.

The analysis of sensory disorders in children with autism is a long process based on the observation of children in a specific environment. It cannot be treated frequently and monitoring the evolution of sensory disorders is either impossible or limited to a period of more than one year. The objective of our study is to define and then use dedicated musical instruments to perceive the intensity of children's responses to different stimuli in order to measure their sensory disorders.

1. Introduction

According to the American Psychiatric Association, autism spectrum disorders (ASD) are neurodevelopmental disorders characterized by deficits in social communication and the presence of limited and repetitive behaviours. Abnormalities in the sensory treatment of ASDs are frequently reported at all ages and may involve all sensory modalities (e.g., apparent indifference to pain, avoidance of certain sounds or textures, perception of unusual odour of objects, search for visual experiences of light or movement [1]). Given the behavioural, neurophysiological and anecdotal evidence of the sensory characteristics of ASDs, the most recent edition of the Diagnostic and Statistical Manual of Mental Disorders [2] presents *hyper- or-hypo-reactivity to sensory inputs or special interests in the sensory aspects of the environment* as a limited and repeated type of behaviour.

Some authors have taken an interest on music and its impact under people with ASD. Indeed, audio stimuli have a greater impact on them than on people without ASD [3]. The response depends of the nature audio stimuli: song [4] and music [5] have a greater influence compared to typically developing people. And conversely, language stimulation cause a less important response compared to typically developing people [4][6]. People with ASD seemed to have better musical skills than those associated with language [7][8][9] [10]. Another benefit of using music for people with ASD is that it seems beneficial to themselves [11]. Therefore, a musical environment is preferred to stimulate people with ASD, but the audio stimuli is not the only one involved in musical activities. Vision, tactile and vestibular stimuli are also involved and cause various responses depending on the specific sensory sensitivity of people.

The idea that initiated our study is to take the opportunity of the existence of the musical activities dedicated to children with ASD to analyze the specific sensory sensitivity of these children in order to identify their sensory disorder. The basic approach of our study is based on the hypothesis that the sensitivity features related to the disorders of the children can be measured by a set of dedicated musical instruments. Such instrument will then play two roles. The main role involving the musical aspects of the instrument will be to stimulate the children by the use of multiple stimuli. According to the metrological aspects of the instruments, the second role will be to perform measurements of the sensory sensitivity.

The horizon of new possibilities related to the confirmation of this hypothesis is extremely large. First, and it's the most important, the periodicity of the measurement will be reduced to one week instead of one year. This will allow to consider to follow the evolution of sensory disorders.

From a measurement science viewpoint, the definition of the measuring instruments needs not only to define the main quantities under the global measurement, but also the link to physical quantities able to be measured by physical instruments.

We present the context of our study in the next section. Then we give the definition of the quantity under measurement. After, we present the possible measurands for the musical instruments and finally, we tackle sensitivity in order to calibration stage to be done.

2. Context of study and methodology

One of the final goals of our study is to design an augmented musical instrument capable of measuring the sensory characteristics of ASDs. The first step in doing this is to determine what are the important characteristics of people with ASDs to use. In this particular context, the traditional measurement based on questionnaires [12] cannot be done. We chose to use visual observation as a starting point to allow an autism specialist to make a diagnosis.

The Annecy conservatory (CRR) develops from several years specific musical activities for children with ASD. During these music workshops, children have the possibility to use various kind of musical instruments under the supervision of music teachers. To assess sensory sensitivity with reference methods, six observation sessions from the music workshop were filmed. The content of the sessions included two programs of 9 and 8 sequences established by the music teacher. The first program contains the following sequences: body percussion to music, playing with a phonotonic and djembe, playing with boomwhackers, instrument cards, playing the statue with hoops, bells, "African music", meditative music, violin. The second program contains other sequences: "melody of first names", electronic drums, conductor's playing, string instrument sequences. In order to best assess the sensory abilities of young people with ASD, two additional sessions were developed in collaboration with the music teacher. The proposed musical program included the following sequences: two opening songs played with sticks and boomwhackers, play with tissues under the strings (guitars and ukuleles), Xylophones with hard and soft red sticks and variations in blade colors, "The lion is dead tonight" with the boomwhackers, Ira Congo sung a capella to finish. A sensory game was also interspersed with the proposed musical sequences to evaluate visual, auditory, tactile, proprioceptive and vestibular modalities. The sensory objects used in this sensory game were chosen to test each modality: the double bass (hearing), pin balls (tactile), a jumping ball (vestibular), bright eggs (vision), sensory balls (proprioceptive).

We filmed the music workshop for several children. Then, we annotated the videos using ELAN software to characterize the symptomatic attitude of ASDs. These observations are being analysed to check their consistency with the conventional diagnosis. These results related to Psychology sciences are not presented in this paper that is concerned by the Measurement science; we focus on the ability of ASD to be measured by sensors. In the long term, these sensors will be integrated into musical instruments made available during the workshops. The next step in this process is to design such a musical instrument that can measure the sensory

profile of children with ASD. To do this, it is necessary to associate, to each symptomatic sensory attitude to be measured, the sensors that allow it. This article focuses on the proposal of this association to establish the sensory profile by measuring ASDs from sensors that will be placed in an object, particularly in a musical instrument made *sensitive* in this way.

3. Definition of the quantity under measurement

Sensitivity studies in children with ASDs indicate that sensory characterization is achieved by identifying the intensity of hypersensitivity and hyperreactivity to stimulation related to hyposensitivity and hypersensitivity respectively.

Actually, responsiveness is never considered as a one-dimensional quantity because a child's sensitivity can be both hypo and hyper. This appears especially on the result given by an analysis based on Dunn's sensory profile [13]. Bogdashina, who considers not only the sensory disorders but also any sensory experiences, proposed to split the global sensory sensitivity on 7 modalities that are: vision, hearing, taste, smell, tactile, proprioception, vestibular [14]. Even if the hyposensitivity and hypersensitivity can be detected simultaneously for a given modality, this situation occurs rarely. The sensitivity is then defined by its threshold. A low threshold indicates a hypersensitivity and a high threshold indicates a hyposensitivity.

In the field of Psychology, the measurement approach is based on the clinical observation of the behavior's manifestations of the hypo/hyper sensory sensitivity. For example, approaching a noisy object to the ear is a manifestation of a hyposensitivity on the hearing modality. This approach conforms with the basic principles of measurement. The involved process performs observations of the manifestations of a quantity. Indeed, this quantity is the sensory sensitivity threshold, and each manifestation observation contributes to the production of an observation statement that defines an intersubjective evaluation as defined by Mari [15].

Bogdashina proposed to evaluate separately the sensitivity for the 7 modalities with a questionnaire made of 232 questions. Each question is related to the occurrence of a behavior that expresses an hypo or hyper sensitivity. For each modality, aggregation is performed by counting the number of observations of hypersensitivity-related behaviours and the number of non-observations of hyposensitivity-related behaviours. The final measurement result is obtained by a normalisation with the number of questions for the given modality.

The measurand, i.e. the quantity under observation that we will name the *multimodal sensitivity*, is defined by a set of 7 measurands : formally the sensory sensitivity thresholds for each of the 7 modalities. The measurement of measurands related to each modality is then performed with an ordinal scale, i.e. a scale that preserves the ordinal relations.

In order to create references for a future calibration of the augmented musical instruments, our study was first focused on analyse of the sensitivity of 4 children with ASD by the way of psychological approaches. The chosen approach is an analysis based on the Bogdashina questionnaire limited to the 5 modalities: vision, hearing, tactile, proprioception and vestibular . Figure 1 presents a synthesis of the analyse of the sensory sensitivity of the 4 children with the Bogdashina's questionnaire. For confidentiality reasons, the children names had been changed.

4. Definition of the possible measurands for the musical instruments

As the Conservatory organizes musical activities, musical instruments will be augmented to allow them to perceive their environment, and more specifically to perceive the interaction that children have with them. They may also be able to stimulate children through the production of sounds, lights or movements. As augmented musical instruments can only detect or act on physical quantities, they cannot directly measure children's *multimodal sensitivity*. If we consider each modality (measuring the taste sensitivity and the smell sensitivity is a quite complex process and these two modalities are not included in our study) the *multimodal*

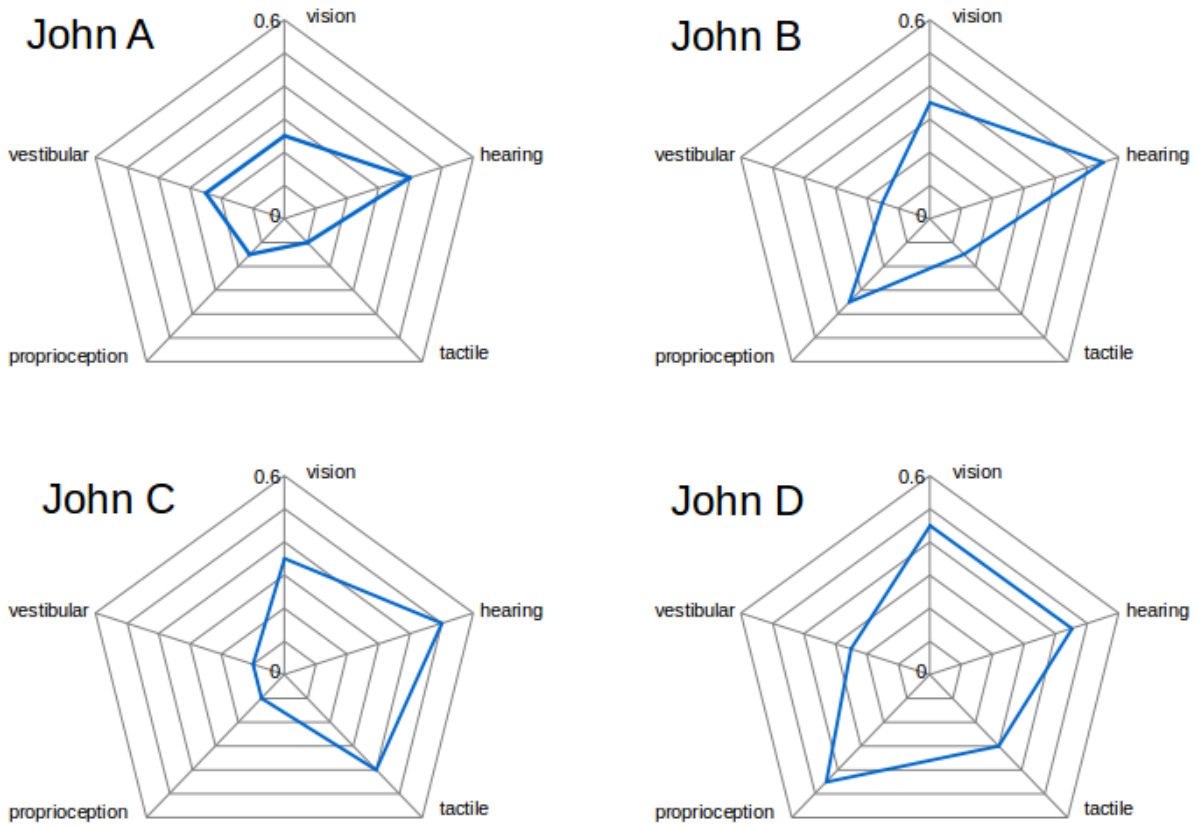


Figure 1. Bogdashina synthesized result for 5 sensory modalities. On the scale, 0 leads to a sever hyposensitivity and 0.6 leads to an important hypersensitivity, and 1 to a sever hypersensitivity

sensitivity is restricted in our study to 5 modalities: vision, hearing, tactile, proprioception, vestibular.

In our approach, each augmented musical instrument (AMI) is formally a set of sensors and actuators, and is able to communicate with the other instruments. Actually, an AMI holds all the properties of an actor of the Internet of Things (IoT). Furthermore a group of AMIs is defined as a measuring experiment around the children, each measuring experiment being defined relatively to the observation of a children behavior and each behavior being a manifestation of a hypo/hypersensitivity of a given sensory modality. The goal is to let the AMIs observe and identify the hypo/hypersensitivity manifestations.

The proposed tables 1 to 4 list the behaviors under observation for each modality. These lists, defined by a psychologist, are similar to the Bogdashina's questionnaire but are dedicated to the observation by sensors. The column 2 of each table associates with each behavior one or more quantities that must be measured by the AMIs in order to identify the occurrence of the given behavior. The column *Devices* gives the pertinent sensors, actuators and processes the AMIs must hold to participate to the measuring experiment (detailed in table 5).

According to a group' ability to perform multiple experiments to detect the occurrence of the listed behaviours, the link between the intensity of the behaviour and the *sensitivity* remains to be established. Two main options are available: apply existing methods based on knowledge of the relationship of each behaviour with hyposensitivity/hypersensitivity, or establish this relationship through a learning method. Especially, the Rash method, already successfully used in the field [16], is under study.

5. Conclusion and perspectives

The ultimate objective of our work is to automate the production of the sensory profile of children with sensory autism disorders (ASD). We took the opportunity of music workshops to convert musical instruments into augmented musical instruments by making them sensitive to the children who manipulate them. This paper presents the early phase of this work. It shows the possibility to link the most recent approaches in psychology related to the identification of the sensory sensitivity with the measurement science. As a reference, we produced sensory profiles using the Dunn/Bogdashina observation grid. We proposed an alternative observation grid dedicated to the observations performed by the augmented musical instruments.

The next steps in this work is the finalization of the firsts augmented musical instruments able to follow the proposed observation grid and with respect to the safety of the children. After the firsts observation statements given by the instruments, a calibration phase based on the use of the reference sensory profiles is planned for the next year. Finally a toolbox including a set of connected augmented musical instrument will be proposed. The automation of the measurement of sensory profiles is a great interdisciplinary challenge. It needed to interpret a psychological analysis with the concepts of measurement science in order to maximise the common data sources between the 2 approaches. The results are very important for children with ASD. Compared to manual analysis, the automation allows to drastically reduce the analysis period and to reduce the bias introduced by the subjectivity of the observers. It opens up new possibilities not only in monitoring sensory disorders but also in their early detection. Even if using musical instrument came from an opportunity, they have the merit of reducing the impact of the bias due to children's fatigue in relation to a simple object or toy.

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Annexes

Table 1. Hearing sensitivity.

| Behavior | Quantity under observation | Devices |
|---|-----------------------------------|---------------|
| Draws near an AMI producing noise | distance (child/AMI) | $s_1 s_2 s_3$ |
| Fends off an AMI producing noise | AMI motion | $s_4 p_1$ |
| Expresses interest for an AMI producing noise | touch frequency | $s_5 s_6$ |
| Turns his head to his talking peers | AMI motion if used as a pointer | $s_4 p_2$ |
| Turns his head to a noise | AMI motion if used as a pointer | $s_4 p_2$ |
| Reacts to a singing voice | AMI motion if used as a pointer | $s_4 p_2 p_3$ |
| Reacts to a speaking voice | AMI motion if used as a pointer | $s_4 p_2 p_3$ |
| Sings spontaneously | sound (singing character of song) | $s_7 p_1$ |
| Reproduces a short melodic sequence | distance between sequences | $a_1 s_7$ |
| Requests a louder sound | pressure, frequency (on a button) | $a_1 s_8$ |
| Requests a tone change | pressure, frequency (on a button) | $a_1 s_8$ |
| Requests a tempo change | pressure, frequency (on a button) | $a_1 s_8$ |
| Requests a timbre change | pressure, frequency (on a button) | $a_1 s_8$ |

Table 2. Vision sensitivity.

| Behavior | Quantity under observation | Devices |
|--|------------------------------------|---------------|
| Looks the AMI | head orientation | $s_1 s_2 s_3$ |
| Get closer to the AMI when flashing | distance (head/AMI) | $s_4 p_1$ |
| Caresses the AMI when flashing | vibration, acceleration, frequency | $s_5 s_6$ |
| Exchange of glances towards the same direction | eye direction | $s_3 s_9$ |
| Eye-to-eye contact with peers | eye direction | $s_3 s_9$ |
| Eye-to-eye contact with the teacher | eye direction | $s_3 s_9$ |
| Is oriented towards the teacher | AMI motion and location | $s_3 s_4$ |
| Requests a hue change | pressure, frequency (on a button) | $s_8 a_3$ |
| Requests a brightness change | pressure, frequency (on a button) | $s_8 a_3$ |
| Requests a saturation change | pressure, frequency (on a button) | $s_8 a_3$ |

Table 3. Tactile sensitivity.

| Behavior | Quantity under observation | Devices |
|---|------------------------------------|-----------------------|
| Manipulates the AMI | AMI motion | s_4 |
| Touches the AMI | distance (fingers/AMI), frequency | $s_5 s_6 s_8$ |
| Caresses the AMI | vibration, acceleration, frequency | $s_5 s_6 p_1$ |
| Fends off an AMI with a given texture | AMI motion | $s_3 s_4 s_5 s_6 a_4$ |
| Requests a texture change | pressure, frequency (on a button) | $s_5 s_6 s_8 a_4$ |
| Uses AMIs with similar textures | frequency, duration | $s_8 a_4$ |
| Hits on the AMI | AMI motion | $s_4 s_5 s_6 s_8$ |
| Moves away from the AMI | distance (user/AMI) | $s_1 s_2$ |
| Manipulates or touches the AMI when it vibrates | AMI motion, distance (fingers/AMI) | $s_4 a_5$ |

Table 4. Vestibular and proprioception sensitivity.

| Behavior | Quantity under observation | Devices |
|--|----------------------------|---------------------|
| Moves the AMI in rhythm | AMI motion | $s_4 p_1$ |
| Sways with the AMI | AMI motion | $s_4 p_1$ |
| Swings with the AMI when it makes noise | AMI motion | $s_4 p_1 a_2$ |
| Turns with the AMI | AMI motion | $s_4 p_1$ |
| Manipulates the AMI abruptly | AMI motion | $s_4 p_1$ |
| Coordinates his movements to play the AMI | distance (fingers/AMI) | $s_5 s_6 s_8$ |
| Appropriately touches the AMI to produce a sound, a rhythm | distance (fingers/AMI) | $s_5 s_6 s_8$ |
| Contact with his own body: he touches his mouth, his hands | skeleton motion | $s_{10} s_{11} p_4$ |

Table 5. Sensors, actuators and processes involved.

| | | |
|---|-------------------------------|----------------------------|
| s_1 : telemeter | s_2 : proximity sensor | s_3 : geolocation device |
| s_4 : 9Dof gyro/compass/accelerometer | s_5 : capacitive sensor | s_6 : inductive sensor |
| s_7 : microphone | s_8 : push button | s_9 : eye-tracker |
| s_{10} : camera | s_{11} : depth camera | |
| a_1 : music synthesizer | a_2 : voice synthesizer | a_3 : LED |
| a_4 : adaptable texture | a_5 : vibration motor | |
| p_1 : signal processing | p_2 : acoustic localization | p_3 sound recognition |
| p_4 : gesture recognition | | |