# The Sound of Actuators in Children with ASD, Beneficial or Disruptive?

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**Abstract.** It is often overlooked in human-robot gestural interactions that, robot produce sound when they move. That aspect might be either beneficial or detrimental to the interaction, but it should be taken into account, especially in the context of robot-assisted therapy.
In this paper, we therefore considered sensory perception in the case of typically developing children and children with Autistic Spectrum Disorders and designed a pilot study with twenty participants to evaluate the impact the sound of actuators has on a rhythmic gestural interaction. Participants were asked to perform a waving-like gesture back at a robot in three different conditions: with visual perception only, auditory perception only and both perceptions. We analyze coordination performance and focus of gaze in each condition. Preliminary results indicate that the sound of actuators might be beneficial for children with autism and only slightly disruptive for typically developing children.

**Keywords:** ASD, motor coordination, sensory processing

## 1 Introduction

During robot assisted therapy, sensory and cognitive aspects of the interaction can influence it to the detriment of its use and effectiveness.

Interpersonal interactions are inherently multimodal but in the case of gestural human-robot interactions, the human partner perceives the movements from the robot but also the sound produced by the robot motors. In that case, these two modalities (visual and auditory) are congruent, which, according to research in neuroscience, might be confusing for the human perception system. Moreover, research also shows that the human brain has different ways of processing different sensory stimuli and that sensory dominance may appear. Sensory processing also depends on the context:

– **Vision may be dominant over audition in spatial localization.** A modality-appropriateness hypothesis suggests that "the human perceptual system is cognizant of the fact that vision is a more trustworthy modality for spatial localization than audition and proprioception and, for this reason,

it is more closely attended" [28]. Moreover, visual information does not have the strong alerting capacity of auditory signals and therefore people are predisposed to direct their attention towards visual stimulation predominantly [21].
- **Audition may be dominant for temporal judgments.** [12] showed that the auditory perception can severely alter or even remove the visual perception when the stimuli are spatially and temporally congruent. They produced white noise bursts through headphones and observed decreased visual orientation discrimination performance. However, suppression occurs only if the sound and visual stimuli are presented in an ipsilateral, spatially congruent manner and in a temporally congruent manner.

This co-existence of two sensory stimuli is particularly a concern for rhythmic interactions. Rhythmic interactions trigger the emergence of involuntary movement coordination when two humans interact with each other (walking, clapping, drumming...). Synchrony is pervasive in biological systems and unconsciously facilitates the creation of emotional connections. Human-Robot coordination or imitation is a promising research subject in socially assistive robotics as several neurological disorders such as Parkinson's, cerebral palsy, autism do not affect synchronization abilities. It has therefore been widely used with a therapeutic goal, particularly for children with autism [5,25], but also for motor rehabilitation [9].

Gault et al. showed that the auditory modality facilitates discrimination and reproduction of rhythmic patterns [6]. Besides, Repp et al. conducted a study on sensorimotor coordination where participants were required to tap their finger in rhythm with an auditory or visual sequence and report whether a time-shifted event was present [23]. Results showed that the visual information yielded greater variability of movement, smaller involuntary phase correction response and poorer time-shifted event detection than the auditory information. After that, participants were subjected simultaneously to both auditory and visual sequences and were instructed to ignore the auditory information. Analysis evidenced that involuntary phase correction response depended more on auditory than on visual information and that variability was similar to the auditory sequences. Moreover, other research also showed that people have greater difficulty synchronizing finger taps with a visual signal compared to an auditory signal [1,3,4]. It has also been argued that the motor system is more responsive to auditory than to visual input [4], which has been confirmed by [13,27] and suggested that there are different timing mechanisms in the two modalities [15].

Beyond the disruptive aspect of combining sensory modalities, it has also proved to be useful, for example, [26], in a Parkinson gait rehabilitation study, showed that auditory and visual perception and both perceptions all improve different aspects of gait. This evidences that, in some cases, the auditory and visual perception can reinforce each other.

We also showed in [14] that the sound of robot actuators disturbs the motor coordination of neurotypical adult subjects in a waving rhythmic task. The sensory processing of children with ASD is however different and this sound may affect them in other ways. Besides, this is a relevant question since robot actuators always produce a sound and this may be perturbing in a therapeutic setting.

The development of sensory systems in children appears to be related to their developmental process [22,29]. In young children, proximal receptors (touch, taste, smell) are more developed than distal receptors which gradually supersede the former with age.

ASD is usually associated with abnormal sensory processing where a stimulus can either trigger no reaction or a disproportionate/exaggerated response [8]. Contrary to neurotypical children, children with autism are known to prefer the use of proximal receptors (touch, taste) rather than distal receptors (vision, audition) [7,24]. However, both neurotypical and children with autism respond more to a visual stimulus than to an auditory stimulus [17,18,11]. In a multisensory study, [10] subjected children to multi-sensory stimuli. When combining visual and auditory stimuli, neurotypical children and children with ASD reacted predominantly to vision. However, for the combination of touch and sound, neurotypical children responded more to sound while children with ASD responded more to touch.

Children with autism may exhibit an unpredictable or inconsistent motor response to sensory stimuli, that is either an inhibited or facilitated motor response [19]. Moreover, [11] showed that a visual stimulus is more likely to elicit a movement stimulation than an auditory stimulus.

In this paper, we therefore considered sensory perception in the case of typically developing children and children with Autistic Spectrum Disorders and designed a pilot study to evaluate the impact the sound of actuators has on a rhythmic gestural interaction.

## 2 Materials and Methods

The goal of this study is to study the sensory dominance of neurotypical children and children with ASD during a human-robot rhythmic interaction. This will allow us to better understand sensory processing in such interactions and thus to better design motor therapies involving a robot.

### 2.1 Study Design

This study replicates the sensory dominance study introduced in [14]. Participants were asked to wave back at the Pepper[3] robot [20] (Softbanks Robotics) depending on three conditions that subjected the participants to various sensory stimuli. The study session lasted about one hour.

Parent was asked to fill in the Bogdashina sensory profile [2] for their child beforehand. This questionnaire allowed us to assess the sensory dominance of each child.

[3] `https://www.softbankrobotics.com/emea/en/pepper`

During the study session, the child and their parent were first asked to answer some questionnaires. Afterwards, the robot was switched on and the child and his or her parent were free to interact with it in its built-in interaction mode. This part could last between ten and twenty minutes depending on the interest the child exhibited.

Then, the child was equipped with TEA [4] Motion sensors on the right arm. The sensors are calibrated at the beginning of the session with the resting pose of the child (standing, arms straight against the body). They provides us with quaternions. The child was seated in front of the robot, their arm resting on a pillow. The child was instructed to wave back at the robot under various conditions:

- a baseline condition where the child could hear and see the robot (AV)
- a condition where the child could not see but hear the robot due to a removable panel (A)
- a condition with white noise through headphones where the child could not hear the robot (V)

The child was videotaped during the interaction.

Finally, the child and their parent were asked again to answer questionnaires. Those questionnaires are out of the scope of this paper and we will, therefore, not report on those results here.

### 2.2 Participants

Twenty children participated in the study. Five children were autistic (only boys, 9.6 ± 2.07 years old). The other fifteen were neurotypical (including 7 girls, 9.1 ± 2.0 years old). Two neurotypical children were excluded from the study results due to a motion sensor malfunction. Moreover, due to the COVID-19 outbreak, we had to cancel additional studies and recruitment was interrupted. This study was approved by Inria ethical committee. The accompanying parent of each child gave a written informed consent.

### 2.3 Materials

**The Robot** The Pepper robot was programmed to wave according to a sinusoidal signal. The signal frequency varied from one interaction to the other ($0.9Hz$, $1.0Hz$ or $1.1Hz$) to avoid frequency acclimatisation. The robot woke up from its rest state at the beginning of each series of interactions. Waving periods were indicated by an auditory stimulus and by the robot eyes becoming green, they were unlit otherwise. At the end of each series, the robot returned to its rest state. Each condition consisted of a series of nine waving interactions.

[4] https://www.teaergo.com/products/tea-captiv-t-sens-motion-imu/

**Gaze analysis** Using the video of the child, we can extract gaze direction (See Fig. 1). The program [5] first detects the face in the picture, then identifies face landmarks to extract the eyes. Applying a threshold on the image allows to extract the pupil coordinates.

**Coordination analysis** The coordination performance is computed using the Phase Locking Value (PLV), which provides a score between 0 and 1 (1 being fully coordinated).

The Phase Locking Value (PLV) has been introduced by [16] to measure coordination in brain signals. It relies on the assumption that both signals are locked with a constant phase difference but the PLV allows for deviations and evaluates this spread. First, the Hilbert transform is computed, providing the instantaneous phase $\phi$ for each signal, then the instantaneous PLV can be obtained:

$$PLV(t) = \frac{1}{N}\left|\sum_{i=0}^{N} e^{j(\phi_1(i)-\phi_2(i))}\right| \tag{1}$$

with $N$ the sliding window size, $j = \sqrt{-1}$, $\phi_k$ the instantaneous phase of signal $k$.

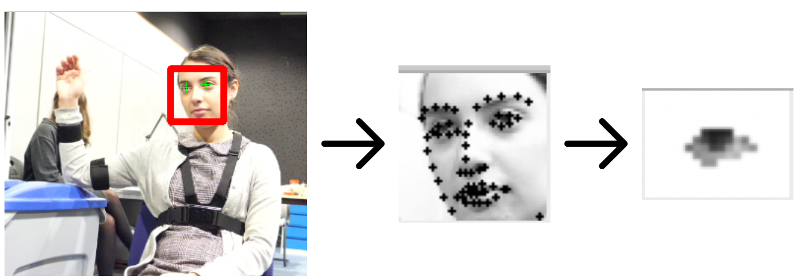

**Fig. 1.** Illustration of the gaze extraction process: Face detection → landmarks detection → eye extraction. The subject is equipped with motion sensors in the first image: one on the arm, one on the forearm and one in the back placed on a harness

# 3 Experimental Results

## 3.1 Coordination performance

To ascertain that the child was actually looking at the robot when required, we extracted the gaze direction from the video. Interactions where the child's gaze direction varied too much were excluded from the data analysis. It is worth

[5] `https://github.com/antoinelame/GazeTracking`

mentioning that children's gaze was more focused on the robot in the V condition (ASD: 48.2%, neurotypical: 52.8%) than in the AV condition (ASD: 22.2%, neurotypical: 26.9%).

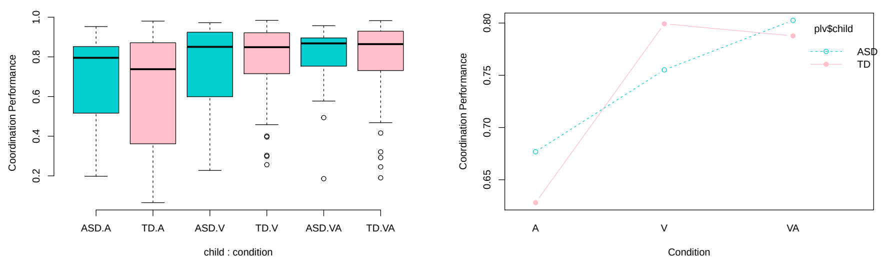


**Fig. 2.** Coordination performance results. Up: boxplot representation of the coordination performance according to condition (AV, V, A) and child diagnosis (ASD, neurotypical). Down: Interaction effect between the conditions

Preliminary results show that autistic children were more coordinated in the AV condition while neurotypical children were similarly coordinated in the AV and V conditions. See Table 1 and Figure 2 for an overview of the results.

| condition | AV | A | V |
|---|---|---|---|
| neurotypical | $0.79 \pm 0.20$ | $0.63 \pm 0.27$ | $0.80 \pm 0.17$ |
| ASD | $0.80 \pm 0.17$ | $0.76 \pm 0.23$ | $0.68 \pm 0.23$ |

**Table 1.** Average coordination performance (AV: auditory-visual condition, A: auditory condition, V: visual condition)

A two-way ANOVA reveals a significant difference between the conditions ($p < 0.001$) but not between the different children diagnosis ($p = 0.28$). A post-hoc Tukey test on the conditions showed a significant difference between the AV and A conditions ($p < 0.001$) and between the V and A conditions ($p < 0.001$), but not between the AV and V conditions ($p = 0.99$).

A two-way ANOVA also reveals a significant difference between age groups ($p < 0.001$) (See Fig. 3). A post-hoc Tukey test on the age groups showed a significant difference between six year-olds and every other age group ($p < 0.001$).

### 3.2 Sensory Profile

The sensory profile revealed that most children with ASD appear to be more sensitive to visual stimuli (See Table 2).

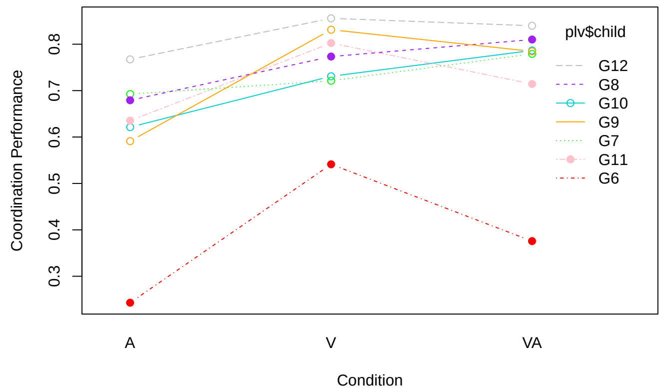


**Fig. 3.** Coordination performance for each age group, G$X$ indicates age group X, for example G6 comprises 6 years old. (See details in text)

| AV | V | A | PSV | PSA |
|---|---|---|---|---|
| 0.69 | **0.80** | 0.70 | **8** | 4 |
| 0.66 | **0.83** | 0.66 | 11 | **12** |
| 0.92 | **0.93** | 0.86 | **13** | **13** |
| **0.82** | 0.63 | 0.64 | **8** | 5 |
| **0.68** | 0.48 | 0.53 | **9** | 7 |

**Table 2.** Summary table with Coordination performance scores and sensory profile scores (PSV: visual sensory profile; PSA: auditory sensory profile) for the 5 children with ASD in the study

For the neurotypical children, only two appear to be more sensitive to visual stimuli and five to auditory stimuli. A statistical analysis reveals no correlation between sensory profile results and coordination performance

## 4 Discussion and Conclusion

Preliminary results showed that both neurotypical children and children with ASD coordinated better with a visual signal or with a visual-auditory combination than with an auditory signal alone. This predominance of vision over audition is in concordance with previous studies [11,10,18,17]. Besides, we observed that the children tend to look less at the robot when they can also hear the sound of the robot motors than when they cannot. While this should obviously be confirmed with a higher number of children, the children results appear to differ from the ones from the adults. While adults were perturbed in their coordination when subjected to both visual and auditory stimuli, this combination may reinforce the children's interaction and lead to better coordination.

This study encountered a few limitations, the main being the limited number of participants, particularly children with autism, which makes the comparison between the neurotypical sample and the autistic spectrum disorder sample somewhat unbalanced. While these preliminary results already give us interesting information, we would expect the overall results would have been more significant with more participants.

While the results are preliminary and need to be validated with more children, they are encouraging as children enjoyed interacting with the robot and the sound of actuators appears to facilitate coordination, at least for children with ASD.

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