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Inter-individual Differences in Conscious and Unconscious Robot-Child Interaction in Children

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Abstract. Combined cognitive neuroscience knowledge with psychiatry and engineering knowledge, we have used the paradigm of listener-speaker to analyse un/conscious processes in association with emotion and language in neurotypical children aged 6 and 9 years old. The speaker was always a child; the listener was a Human or a Robot InterActor, i.e., a small robot which reacts to speech expression by nodding only. Unconscious nonverbal emotional expression reflected in physiological data, i.e., heart rate, as well as conscious process mirrored on behavioral data, i.e., number of nouns and verbs in addition reported feelings, were considered. The results showed that 1) the heart rate was higher for children aged 6 years old than for children aged 9 years old when the InterActor was the robot; 2) the number of words (nouns and verbs) expressed by both age groups was higher when the InterActor was the human. Unconscious and conscious processes would not only depend on natural environments but also on artificial environments such as robots.

Key words: paradigm of listener-speaker, cardiovascular activity, emotion, language un/consciousness

1 Introduction

The investigation of consciousness is one of the enigma facing the scientific perspective. There are many theories of what consciousness is. According to one of them, consciousness and human consciousness in particular is defined as the having of perception, feelings and thoughts of the internal and the external world [1]. Multimodal verbal and nonverbal interactions are joined with emotions in a continuous dynamic neuronal complex that constitutes consciousness. Consciousness mirrors high level processes such as perception, action, language, and emotion that are linked with the cortical functioning. It is deeply interwoven with unconsciousness that is associated with low level processes such as respiration, transpiration and heart rate that are linked with sub-cortical areas. For the study of consciousness, nothing makes sense except in light of development display.

In newborns, facial expressions and voice degree are the first mean of communication with the outside world [2, 3] what may be referred to as minimal consciousness [4]. From the age of 4 months, the child readily discriminates negative and positive emotions [5, 6]. Different types of smiles correspond to different degrees of emotional degree [7]. As children can communicate only about the world as the world is organized in conscious perception, conscious perception occurs to be a prerequisite of human language [8, 9]. But children acquire language through both conscious and unconscious processes. The relational concept presupposes bilaterally dependent and constitutive linkage between conscious verbal expressions and unconscious nonverbal expressions [10]. Beyond 8 months, children intellectualize each basic emotion and learn to relate facial and gestural expressions, context and words [11, 12]. The ability to use language to name the emotional feeling and expressions occurs between 2 and 10 years [6, 13, 14]. A relatively smaller number of words for naming emotions exists in young children than in older children, reflecting different levels of maturity in consciousness [13]. As humans develop and mature, un/consciousness (including emotions) is considered to be the core nucleus of language [15]. The capacity to generate thoughts and concepts for ourselves and for the others which can be verbally expressed with the aim to communicate is at the origine of what is arguably one of the trademarks of human development [8, 16].

With this in mind, we can conceive a verbal and nonverbal communication construct between two persons: one is the speaker, the other is the listener [16, 17]. The speaker is elaborating a multivariate equation. He is trying to conceptualize within his brain, and encode according to rules of semantics and syntax, and then externalize into spoken form. Speech engenders an avalanche of neuronal responses in the listener. Such neural reaction seems to mirror a multitude of computations associated with multiple processing of information incorporated in the received signal. The received information needs to be decoded and encoded according to linguistics rules and finally encrypted into representation in the neurons of the listener [18]. The listener is computing and trying to solve the proposed equation displaying various conscious verbal and unconscious nonverbal (emotional or not) expressions in response to the utterances of the speaker. Conscious verbal expression necessitates the elaboration of coherent (grammatical and syntactically) sentences. Unconscious nonverbal expression takes the form of head nods, heart rate variation and/or contrasting facial and gestural expressions. Intimately connected with the utterances of the speaker, these responses signify that the utterance is being understood, accepted and integrated [19]. Successful communication between children, for example, requires that both interlocutors accurately interpret the meaning of each other's referential statement. Unquestionably, the ability to understand and share the referential statement of others and to express their own states consciously or unconsciously depends on the cerebral maturity [1]. Conscious (and unconscious) development emerges from dynamic neural connections distributed across many cortical and sub-cortical regions [20].

Neurotypically developing children are able to consider conscious and unconscious conventions, and rules associated with each other's referential statement. This is potentially due to the formation of a neural multimodal network, which naturally follows the evolution of the brain [21, 22]. Different studies emphasize the importance of the prefrontal cortex, temporal and parietal cortices not only for conscious verbal expression and comprehension but also for unconscious nonverbal emotional processes [23, 24]. As such and without doubt, conscious and unconscious functions cannot be confined to the thalamocortical complex alone, but also to lower and higher areas, which are of particular interest from a developmental viewpoint [20]. The dynamic modeling of cortical thickness associated with the development of language, emotion and consciousness increases gradually from early childhood, i.e., 5 years to midchildhood i.e., 9 to 11 years) with sequential emergence of three important cortical regions: temporal poles, the inferior parietal lobes and the superior and dorsolateral frontal cortices [25]. Sub-cortical regions develop in combination [26]. As a consequence, consciousness (and unconsciousness) gradually follows that dynamic modeling which is naturally characterized by intra and inter individual differences. At each age of development these differences are associated with the differential degree of brain plasticity [25].

In the context of an interdisciplinary study (cognitive neuroscience, psychiatry and engineering) and with the aim to compare conscious verbal expressions (reflected by the number of the produced nouns and the verbs as well as by the reporting feeling) and unconscious nonverbal emotional expressions (given by the heart rate) in children aged 6 and 9 years, we used the paradigm of "speaker-listener" [16, 17]. The speaker was always a child; the listener was a human InterActor or a robot InterActor, i.e., a small robot which reacts to speech expression by nodding only. Given the fact that at both intra-individual and inter-individual levels, dynamic neural differences characterize children aged 6 and 9 years old, our general hypothesis was that their conscious verbal expressions and unconscious nonverbal (emotional) expressions would differ. A recent study has shown that children with mild-moderate autism (with 6 years old in terms of developmental age) who present less brain activity, because of the neurodevelopmental disorder, showed more important nonverbal expression (unconscious reactions) when the InterActor was the Robot than when the InterActor was the human [17]. If such finding is transposed to neurotypically developing children, we can hypothesize that children with less brain maturity, i.e., 6 years old would display more nonverbal expression with the robot, than children with more brain maturity, i.e., 9 years old: the lesser the brain activity, the more the unconscious nonverbal emotional expression. Indeed, in the aforementioned study the interpretation was that children with autism are more interested in the InterActor Robot especially because of its predictability, i.e., defined degree of variability in reactions. As such, it stands to reason that neurotypical children of the present study would be more interested in the human InterActor complexity. Additionally and given the fact that conscious and unconscious processes are interwoven, we have hypothesized that inter-individual differences would exist not only in unconscious nonverbal emotional expressions but also in conscious verbal expressions between 6 and 9 years old children.

2 Method

2.1 Participants

Two groups of children “6 years old” and “9 years old" participated in the study. Twenty children (10 boys and 10 girls) composed the “6 years old group”; twenty children (10 boys and 10 girls) composed the “9 years old group”. The developmental age of the first group ranged from 6 to 7 years old (mean 6.3 years; sd 4 months). The developmental age of second group ranged from 9 to 10 years old (mean 9.2 years; sd 5 months). All children were healthy. Children attended regular schools and had no learning disorders, neurodevelopmental diseases or cardiac or psychiatric problems as reported by their teachers. Their academic achievements were standard in their school. The study was approved by the local ethic committee and was in accordance with the Helsinki convention. Anonymity was guaranteed.

2.2 Robot

An InterActor robot, i.e., a small toy robot, called "Pekoppa", was used as a listener [27]. Pekoppa is shaped like a bilobed plant and its leaves and stem make a nodding response based on speech input and supports the sharing of mutual embodiment in communication (Figure 1). It uses a material called BioMetal made of a shape-memory alloy as its driving force. The timing of nodding is predicted using a hierarchy model consisting of two stages: macro and micro (Figure 2). The macro stage estimates whether a nodding response exists or not in a duration unit, which consists of a talkspurt episode T(i) and the following silence episode S(i) with a hangover value of 4/30 s. The estimator Mu(i) is a moving-average (MA) model, expressed as the weighted sum of unit speech activity R(i) in (1) and (2). When Mu(i) exceeds a threshold value, nodding M(i) also becomes an MA model, estimated as the weighted sum of the binary speech signal V (i) in (3). Pekoppa demonstrates three degrees of movements: big and small nods and a slight twitch of the leaves by controlling the threshold values of the nodding prediction. The threshold of the leaf movement is set lower than that of the nodding prediction.

Fig. 1 Pekoppa

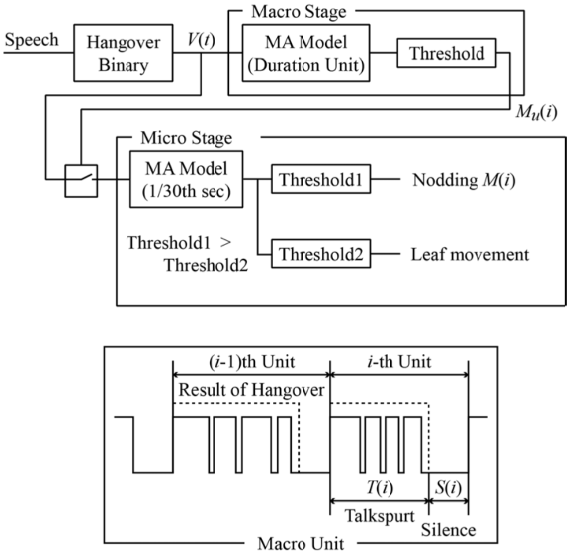

Fig. 2 Listener's interaction model

$$M_u(i) = \sum_{j=1}^{J} a(j)R(i-j) + u(i) \tag{1}$$

$$R(i) = \frac{T(i)}{T(i) + S(i)} \tag{2}$$

$a(j)$: linear prediction coefficient
$T(i)$: talkspurt duration in the i-th duration unit
$S(i)$: silence duration in the i-th duration unit
$u(i)$: noise

$$M(i) = \sum_{k=1}^{K} b(j)V(i-j) + w(i) \tag{3}$$

b(j) : linear prediction coefficient
V(i) : voice
w(i) : noise

2.3 Procedure: the paradigm of listener-speaker

For both groups, the study took place in a room which was familiar to the children. We defined three conditions: the first one was called “rest condition”, the second was named “Human InterActor” (child-adult) and the third one was called “Robot InterActor” (child-Robot, i.e., child-Pekoppa). The second and third conditions were counterbalanced across the children. The duration of the “rest condition” was 1 minute; the second and third conditions each lasted approximately 7 minutes. The inter-condition interval was approximately 30 seconds [16, 17]. For each child, the whole experimental session lasted 15 minutes (Figure 3).

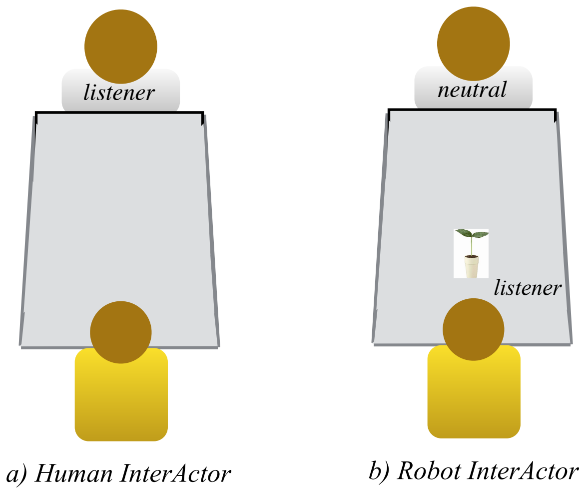

Fig. 3 Paradigm of Listener-Speaker

In order to neutralize a possible “human impact” on children’s behavior, the experimenter was the same person for each child in each condition and group. At the beginning of each session, the experimenter presented the robot to the child explaining that the robot nods whenever the child speaks. Then, the experimenter hid the robot. The session was run as follows: during the “rest condition”, the heart rate of each child was measured in silence. At the end of that condition, the child was also asked to estimate the degree of her/his own emotion on a scale ranging from 1 (the lowest score) to 5 (the highest score) [14]. During the “human InterActor” condition, the child was invited to discuss with the experimenter. The experimenter initiated discussion and after listened to the child acting as the speaker by nodding only. The heart rate, as well as the frequency of words and verbs expressed by each child was measured. During the “robot InterActor” condition, Pekoppa was set to nod movements; the experimenter gave the robot to the child inviting the child to use it. The robot was the listener, the child was the speaker and the experimenter remained silent and discreet. The heart rate and the frequency of words and verbs expressed by the child was recorded once again. At the end of the session, the child was invited to estimate the degree of its own emotion on the same aforementioned scale [16, 17].

2.5 Dependent variables and analysis

The analysis was based on the following dependent variables a) the heart rate (unconscious expression) b) the number of nouns and verbs expressed by each child and (conscious expression c) the degree of feeling (conscious expression) [14, 17]. The data analysis was performed with SPSS Statistics 17.0 [28].

3 Results

The distributions of heart rate, words and feeling reported in both age groups approximates a parametric shape. With such distributions, the mean was chosen as the central index for comparisons. We performed statistical comparisons using the t-student test, the ANOVA's test and the chi-square test ($\chi 2$ Test) to examine differences in heart rate[1], number of words, and degree of feeling reported between the two experimental conditions ("Human InterActor" and "Robot InterActor") for both age groups. The results obtained were very similar. We present here below the results of chi-square test (χ^2 test) which can be used as a substitute for t and ANOVA tests in the present situation [29].

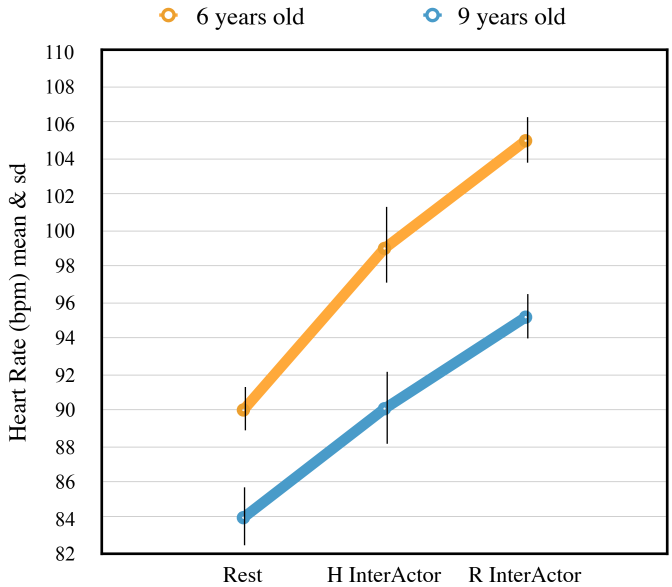

Fig. 4 Heart Rate (bpm)

Figure 4 represents the mean heart rate of both age groups at inter-individual and intra-individual levels.

At the intra-individual level, the statistical analysis showed that relative to the "rest condition", the mean heart rate of 6 years old children was higher when the InterActor was the robot ($\chi 2=6.68$, $p<0.01$) than when the InterActor was the

[1]Heart rate is measured in beat per minute (bpm) using a frequency counter ring (electronic device) placed on the index finger of each child.
The physiological heart rate limits correspond to 95 bpm (±30) at the age of 6 to 10 years.

human ($\chi2=4.09$, $p<0.05$). However, the mean heart rate of children didn't significantly differ when the InterActor was the human or the robot ($\chi2=2.83$, $p>0.05$). Similarly, relative to the "rest condition", the mean heart rate of the 9 years old group was higher when the InterActor was the robot ($\chi2=3.90$, $p<0.05$) than when the InterActor was the human ($\chi2=3.54$, $p>0.05$). To the contrary, the mean heart rate of the 9 years old group didn't significantly differ when the children were with the InterActor robot or with the human ($\chi2=3.10$, $p>0.05$).

At the inter-individual level, the mean heart rate of 6 years old and 9 years old was similar ($\chi2=3.43$, $p>0.05$) in the "rest condition". Analogously, the mean heart rate of 6 years old and 9 years old group didn't statistically differ, when the InterActor was the human ($\chi2=3.78$, $p>0.05$). Conversely, the mean heart rate of 6 years old children was higher from the heart rate of 9 years old children when the InterActor was the robot ($\chi2=6.78$, $p<0.01$).

Two independent judges unfamiliar with the aim of the study completed the analysis of the number of words for each child in each experimental condition ("human InterActor" and "robot InterActor" condition). Both performed the analyses of audio sequences. Inter-judge reliability was assessed using intra-class coefficients to make the comparison between them. The inter-judge reliability was good (Cohen's kappa=0.79).

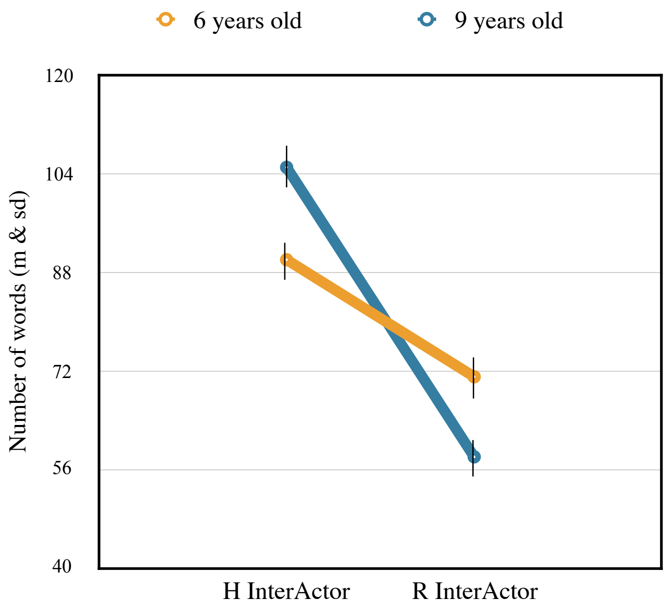

Fig. 5 Number of words (nouns and verbs)

As shown in figure 5, at the intra-individual level and for both age groups, the mean number of words (nouns and verbs) was higher when the children have the human as interlocutor than when they have the robot as interlocutor (χ^2=4.78, p<0.05 for the 6 years aged children and χ^2=7.78, p<0.01 for the 9 years old children). At inter-individual level, the mean number of words was lower in "human InterActor" condition for the children aged 6 years than for the children aged 9 years (χ^2=5.22 p<0.025). In "robot InterActor" condition the mean number of words was higher for the group of 6 years than for the group of 9 years old (χ^2=4.03, p<0.05).

Figure 6 illustrates that at the intra-individual level, the degree of feeling reported didn't differ for both 6 and 9 years old children within each condition: "before the InterActor Robot" and "after the InterActor robot" (χ^2=2.98, p>0.05 for the 6 years and χ^2=3.03, p>0.05 for 9 years children respectively). At inter-individual level, the feeling reporting didn't differ between 6 and 9 years old children before and after the interaction with the InterActor robot (χ^2=2.08, p>0.10 for the 6 years and χ^2=2.56, p>0.10 for 9 years children respectively).

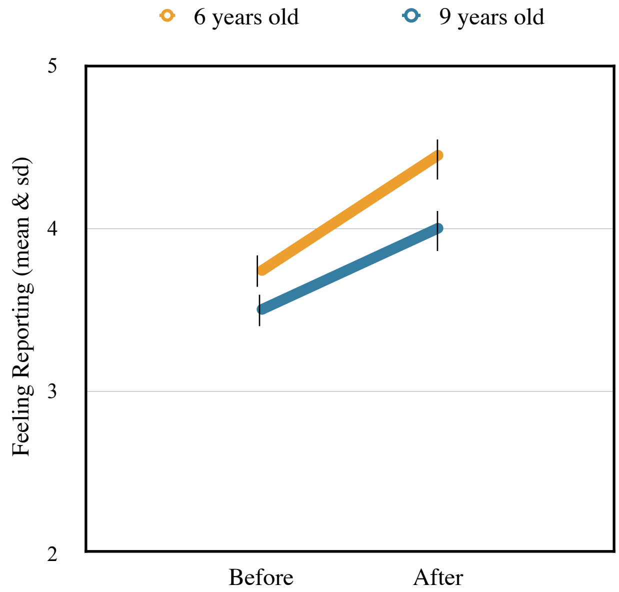

Fig. 6 Degree of feeling reported

4 Discussion

To our knowledge, this study is the first interdisciplinary study which analyzes emotion, language and un/consciousness of neurotypical children using an InterActor in a listener-speaker situation. In the present situation, the speaker was always a child aged 6 or 9 years; the listener was a Human InterActor or a Robot InterActor. Unconscious process i.e., nonverbal emotional expression associated with physiological data (heart rate) as well as conscious processes i.e., verbal expression related to behavioral data (number of nouns and verbs in addition to the feeling reporting) were considered. The results showed that 1) the heart rate was higher for children aged 6 years old than for children aged 9 years old when the InterActor was the robot; 2) the number of words (nouns and verbs) expressed by both age groups was higher when the InterActor was a human. It was lower for the children aged 6 years than for the children aged 9 years; 3) there is no difference between the feeling reported before and after the contact with the InterActor Robot for both age groups.

Surely, our study provides two kinds of results. On the one hand, it has been shown that unconscious nonverbal emotional expression differs between the children aged 6 and 9 years when the InterActor is the robot. Children aged 6 years manifested more nonverbal emotional expression in the presence of the InterActor robot than the children aged 9 years. Moreover, conscious verbal expression was higher when the children had a human as InterActor than when they had the robot as InterActor. Such results are consistent with our hypothesis following which there would be inter individual differences on unconscious nonverbal emotional and conscious verbal expressions between children aged 6 years and 9 years. On the other hand, and for both age groups, the conscious verbal feeling reporting didn't differ before and after the contact with the InterActor Robot. This latter result is inconsistent with our hypothesis.

Concerning the unconscious nonverbal emotional expression, the present findings clearly showed that there is no significant differences of heart rate depending on whether the children were 6 or 9 years old in the rest condition or when the InterActor was a human. Conversely, the children aged 6 years showed a higher heart rate than children aged 9 years, when the InterActor was the Robot. There is no possibility to attribute such a result to an order effect as the order of "Human-InterActor" and "Robot-InterActor" conditions have been counterbalanced across the children. The physiological data we recorded (heart rate) reflects the activity of orthosympathetic and parasympathetic autonomous nervous system, i.e., unconscious functions, which is dynamically (and bidirectionally) connected to the central nervous system, i.e., conscious functions [30, 31, 16, 17]. Physiologically, the inter individual differences of heart rate between 6 and 9 years old children in Robot-InterActor condition would reveal differential peripheral autonomous action of the myelinated vagus nerve [30]. In other words, this would signify a differential degree of unconscious nonverbal emotional maturity. Such autonomous action would reflect inter individual differences of neural activity in the temporal cortex (amygdala included), in the cingulate cortex and in the prefrontal cortex [32]. Developmentally, as skills of state regulation improve, the central nervous system increases to improve greater control over peripheral systems. The autonomous and central systems mature in combination and enable the developing child to become independent in the complex environment. Both systems are still in development in children 6 and 9 years old [25, 33, 34, 35]. In our situation, the heart rate of 6 years old children is higher than the heart rate of 9 years old children when the listener is the InterActor Robot. Such state seems to indicate that children aged 6 years old are more emotionally (and nonverbally) reliant on the InterActor Robot than children aged 9 years old. Interestingly, even if all children verbally reported a better emotional feeling after than before the interaction with the InterActor robot, this difference was not significant. Such behavior would reflect the emergence of a conscious verbal statement from an unconscious nonverbal emotion (such given by the heart rate). Consistent with existing physiological data [25], these findings signify that a difference between level of consciousness exists amongst young children aged 6 years and old children aged 9 years: the lesser the brain development, the more the unconscious nonverbal emotional expression.

Regarding the conscious verbal expression, the present findings indicate that when the InterActor was the Human, the number of words expressed by both age groups was more important than the number of words the children express when the InterActor was the Robot. In the same condition, the children aged 9 years produced more words than the children aged 6 years. Based on the differential degree of brain maturity and consciousness, such variation is in accordance with a constant developmental observation following which the verbal functions continue to mature at 6 and grow up to adulthood [13, 26]. When the InterActor is the Robot, the opposite configuration is noted: the children aged 6 years expressed more words than the children aged 9 years. Once again as referenced above, the children aged 6 years old seemed to be dependent on the environment, i.e., the robot. All in all, for both age groups, conscious verbal expression is more important when the InterActor is the Human, likely because of human complexity.

It has been recently demonstrated that the InterActor robot characterized by predictable nonverbal behavior, i.e., nodding when children speak, better facilitate unconscious nonverbal emotional and conscious verbal expressions of children with autism [17]. With the present study, we have shown that neurotypical children aged 6 and 9 years old better express unconscious nonverbal emotional behavior when the InterActor is the robot and conscious verbal behavior when the InterActor is the human. Contrary to children with autism, neurotypical children would prefer verbally to interact with humans, as human complex nonverbal emotional and verbal behavior does not constitue an obstacle for them in communication. Considering our listener-speaker communication, everything happens as if the InterActor robot could allow 6 and 9 years old aged children to elaborate a multivariate equation encoding and conceptualizing within his/her brain, and externalizing into unconscious emotion (heart rate). The human InterActor, likely due to its complexity, could allow children to externalize the elaborated equation into conscious verbal behavior (words).

5 Conclusion

The present findings would be associated with the development of un/ consciousness. Nonverbal emotional behavior expressed by heart rate is an unconscious automatic activity which, in our case, depends on a minimalistic artificial environment: the InterActor Robot. Verbal behavior given by the words pronounced by the children (nouns and verbs) is a conscious activity which depends on a natural environment: the Human InterActor. Unconscious and conscious processes would not only depend on natural environments but also on artificial environments [35].

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