A tangible, toy-based platform to evaluate the child's social interaction in turn-taking games: promising preliminary results on neurodivergent twins

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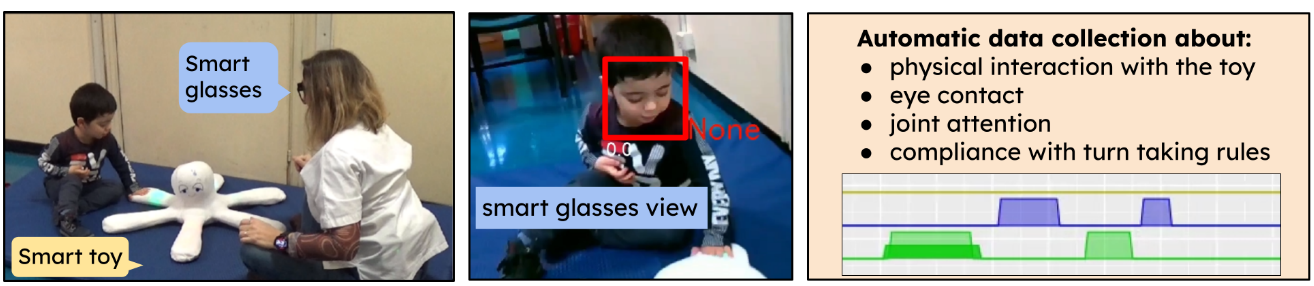

Figure 1: A screenshot of the turn-taking play using the interactive soft toy *Octopus X-8*. The data collected by the toy, combined with the data collected by the smart glasses worn by the therapist for eye contact detection, provide an objective evaluation of the child's social interaction with the caregiver during the play activities (child's face is shown with parental consent).

Abstract

In a previous paper we introduced a smart-toy-based platform, designed to encourage turn-taking play in children and collect behavioural data. In this WiP, we present the preliminary results of a pilot test involving a pair of neurodivergent twins. The initial data analysis indicates that the platform is able to quantify key behavioural indexes – e.g., compliance with turn-taking rules; joint attention; physical interaction with the toy – which reflect the social and play dynamics between child and therapist. We therefore propose the platform as a potential tool for early intervention in neurodevelopmental disorders, both to foster this critical competence and to objectively monitor the child's performance.

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1 Introduction

In Neurodevelopmental Disorders (NDD), and especially in Autism Spectrum Disorders (ASD), one of the behaviours that may be impaired or atypical is turn-taking [9, 14]. This is a form of social interaction in which two individuals alternate a behaviour in a cooperative way, such as during a conversation or playing a board game. This ability relies on a complex, time-accurate integration of visual and auditory – not necessarily verbal – cues [12]. Turn-taking, which is crucial for the development of other key cognitive skills (e.g., language [10], joint attention [15], Theory of Mind [9]) develops very early: it is in fact already present in preverbal communication exchanges between mother and infant [7].

In the context of NDD treatment mediated by technology [1, 11, 18], some experimental, smart toys have been developed to encourage and study turn-taking play in ASD children [2, 8, 13]. In this regard, we introduced in a previous work a toy-based platform designed to stimulate and monitor this competence [17]. In this WiP we present the preliminary results obtained testing the platform with two neurodivergent twins, and show how it successfully manages to capture and quantify some relevant social and play dynamics between child and therapist (fig. 1).

The rest of the paper is organised as follows: Sec. 2 provides an overview of the platform components and of the experimental procedure involving the two participants; Sec. 3 describes the preliminary analysis of the collected data; finally, Sec. 4 illustrates the next steps, planned to refine the tool and to start a large-scale data collection.

2 Material and Methods

2.1 The Platform components: *Octopus X-8* and the *Eye Contact Detector* tool

2.1.1 Octopus X-8. This is a smart soft toy, designed to support turn-taking play in children with NDD, as described in previous works [6, 17, 19]. For the sake of completeness, we summarise its key features here. The toy is a "special" octopus with six tentacles; it produces distinct sensory feedback (coloured lights and sounds) when its tentacles are touched by players according to the game rules (fig. 2). Thanks to inner electronics, the toy can autonomously distinguish between the child's and therapist's touch, enabling the implementation of various turn-taking-based play activities.

Currently, *X-8* offers three different play activities – or *Games* – characterised by increasing complexity[1]:

[1]A demo is available at the link: https://im-twin.eu/video/#x8_functional_features

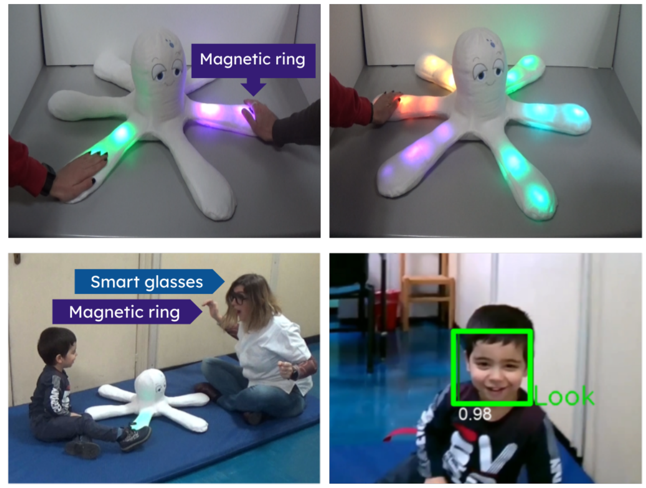

Figure 2: *X-8* autonomously emits different rewarding patterns, depending on the user who touches its tentacles and the current turn-taking rule; this functionality is based on a magnetic ring worn by the therapist, which activates the magnetic sensors embedded in the tentacles. The therapist also wears a pair of *Smart Glasses* for automatic detection of eye contact. Together, *X-8* and the *Smart Glasses* constitute the platform components (child's face is shown with parental consent).

- *Game 1*: whenever a paw is touched, *X-8* emits a sound and the paw glows in green or purple, depending on whether it is touched by the child or the therapist (colours are arbitrary). This game is designed to help the child recognise that the toy responds differently to him and the therapist, and that each player is associated with a specific colour (green for the child, purple for the therapist).
- *Game 2*: all tentacles of *X-8* briefly glow green, indicating that it is the child's turn to touch the toy. If the child touches any of the tentacles, *X-8* emits a sound and produces a rewarding pattern featuring various colours on all tentacles (like a rainbow). After a brief interval, the toy briefly glows purple, indicating that it is now the therapist's turn. If the child touches the toy during the therapist's turn, *X-8* detects the rule violation and does not produce any rewarding pattern. This is the first game based on turn-taking rules.
- *Game 3*: one random tentacle glows either green or purple, indicating which user has to touch the active paw. If the rule is observed (i.e., the right user touches the right tentacle), *X-8* emits a rewarding pattern and a sound. This is the most complex game, as it requires not only compliance with the turn-taking rule, but also the ability to focus attention on the active tentacle.

The current *Game* is selected by a Bluetooth connected App, intended for the therapist. Importantly, the App also receives and stores the data recorded by the toy in a xml file – the *X-8* log – which includes information such as: sensors activities; the label of the selected game; the tracking of game turns; the triggering of rewarding pattern. All of these data is recorded at a sampling rate of 20 Hz, so that the log file provides a timing of all relevant play dynamics [2].

2.1.2 The Eye Contact Detector tool. This is a tool implemented with a pair of commercial camera glasses (or simply *Smart Glasses*), worn by the therapist (fig. 1 and 2). The embedded camera captures videos with a resolution of 640x480 pixels, at 20 frames per second; this frame rate is chosen in order to match the sampling rate of *X-8*. The video is then processed through a computer vision algorithm described in [3, 17], which reliably establishes, given a confidence threshold, if an eye contact with the child is detected[3]. The final output of the processing is an xml file – the *Smart Glasses* log – which reports for each frame the detection (0/1) of this visual behaviour.

Finally, the two logs from *X-8* and the *Smart Glasses* – which together constitute the platform components – are synchronised and merged in one main xml file – the *Platform Log* – which combines information about attentional and play dynamics.

2.2 Experimental procedure for data collection

A pilot test, mainly designed to assess the reliability of data collected by the platform, was conducted with two identical, neurodivergent twins, aged 41 months[4], identified as S_{cd} and S_{au}: the former received a diagnosis of Communication Disorder (CD), while the latter was diagnosed with Autism Spectrum Disorder (ASD). Both brothers exhibited sufficient social behaviour to engage in play with the therapist; however, the qualitative difference between them in terms of attention and social engagement was quite evident, and confirmed by their treating therapist.

The brothers were tested individually[5], for approximately 5 and 7 minutes, respectively. During the test, in which both children showed amusement, the therapist (wearing the *Smart Glasses*) played with the child, testing the three *Games* one after the other. The duration of each *Game* was established by the therapist, based on her experience, when she observed the child's attention beginning to wane (which is why the two sessions had different lengths). A second researcher, in the same room but not involved in the activity, managed the control App and switched between the *Games*, according to the therapist's instructions. The test was recorded by two environmental cameras in addition to the one embedded in the *Smart Glasses*.

The study was approved by the *Italian National ethics committee for clinical research bodies (EPR) and other national public institution (CEN)* [6]. The children's parents provided written informed consent before the start of the experiment, and explicitly authorised the unencrypted use of the children's face for scientific dissemination.

[2]A demo video about data collection capabilities of *X-8* is available at link https://im-twin.eu/video/#data_collection_capabilities

[3]In our tests, the Inter Rater Reliability between the performances of the AI and the human rater is, on average, higher than 0.80. A demo video is available at the link https://im-twin.eu/video/#eye_contact_detector_pilot_test.

[4]In our previous work [17] we only discussed the results concerning S_{cd}.

[5]The test run at the Dep. of Human Neuroscience, Sec. of Child and Adolescent Neuropsychiatry, University of Rome *Sapienza*.

[6]Protocol No. 0029702, 27 February 2022. The study was part of the European-funded project IM-TWIN, https://im-twin.eu/.

3 Preliminary results and discussion

Previously [17] we showed how the data collected by the platform during the pilot test are reliable, i.e. the information in the *Platform Log* match the play and social events recorded by the environmental cameras[7]. In this WiP we proceed to the initial analysis of the information, to highlight the potential of the platform. Specifically, we focus on the following indexes: (a) the durations (measured in *seconds*) of the three play activities and (b) of the eye contacts between child and therapist; (c) the occurrences (measured as *number of events*) when turn-taking rules were observed, and (d) when the child *shares his fun* with the therapist (generally after *X-8* emits a reward), denoted here as Joint Attention (JA) events. The indexes are extracted directly from the *Platform Log* with the exception the last one – JA – which is computed combining the log data about eye contact and the reward triggering by the toy, according to a coding schema discussed below.

The data are presented in the next tables. Since the two participants were tested for slightly different durations, we included beside the row data also additional information, to facilitate a comparison between them. Specifically, in the tables we report the percentage (if data are presented in *seconds*, computed over the total duration of the activity), or the average rate of events per minute, denoted as λ (if data are reported as *number of events*, computed as $\lambda = N \backslash T$, where N is the *number of events* and T the duration of the activity in minutes).

Table 1 shows, for each child, the timing and duration of the three play activities; it provides information about the overall duration of the sessions (5 min., 38 sec. for S_{cd} and 7 min., 29 sec. for S_{au}), and whether there is a preference for any given *Game*. In this case, S_{cd} and S_{au} played fair equally with all three games.

Games timing, S_{cd}				
Game	Start	End	Duration	Percentage
1	0	1:32	92.2 sec	27.2%
2	1:32	3:31	118.9 sec	35.1%
3	3:31	5:38	127.3 sec	37.6%
Session duration			5 min 38 sec	100%

Games timing, S_{au}				
Game	Start	End	Duration	Percentage
1	0:0	2:11	132.0 sec	29.4%
2	2:12	4:56	164.9 sec	36.7%
3	4:56	7:29	152.5 sec	33.9%
Session duration			7 min 29 sec	100%

Table 1: Each table presents the timing of the sessions for S_{cd} and S_{au}. For each of the three play activities, the data shows the *start* and *end* label (in minutes and seconds, frames are omitted), and durations in seconds, along with the percentage of session duration.

Table 2 reports the overall duration of eye contact between children and the therapist. It highlights the first relevant – and expected

[7]The video about S_{cd} session is available at the link https://im-twin.eu/video/#X-8_platform

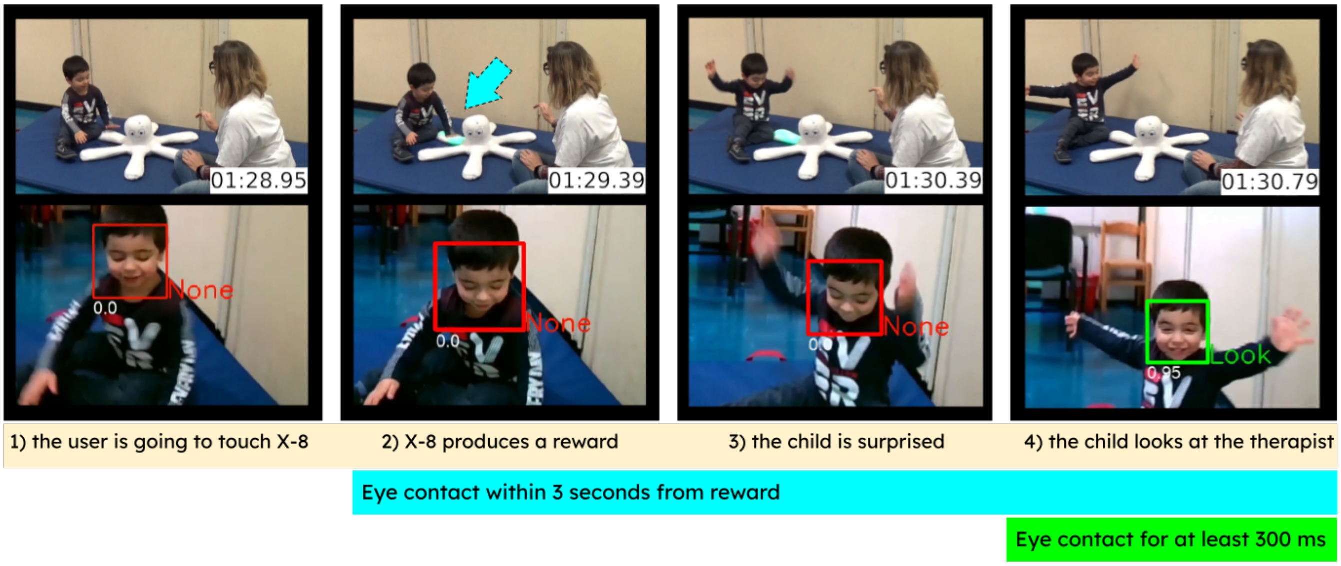

Figure 3: Adopted schema to score a JA event. This behaviour is detected when the child looks at the therapist for at least 300 ms, within 3 seconds of reward triggering (child's face is shown with parental consent).

– difference between the participants: as shown, S_{au} looks at the therapist for less than half the time compared to his sibling. This is reflected also by Table 3, which reports the number of detected JA events during the sessions, with 21 for S_{cd} and 9 for S_{au}.

Duration of eye contact, S_{cd} vs S_{au}			
Subject	Eye contact	Session duration	Percentage
S_{cd}	43.3 sec	5 min 38 sec	12.8%
S_{au}	22.4 sec	7 min 29 sec	5.0%

Table 2: Total duration of eye contact between the participants and the therapist, computed over the whole session.

JA episodes, S_{cd} vs S_{au}			
Subject	No. of JA	Session duration	λ
S_{cd}	21	5 min 38 sec	3.72
S_{au}	9	7 min 29 sec	1.20

Table 3: Number of Joint Attention (JA) episodes, between the participants and the therapist, computed over the whole session.

Before proceeding with the analysis, we clarify what we mean by this index: JA is a widely shared – yet still intuitive – concept in the scientific community [16]; in fact it encompasses a variety of different attentional behaviours, all characterised by a triadic relation involving the self, another individual, and an object of attention. Some authors tried to operationalise the concept, by suggesting coding schemas, generally task dependent [5]. Here we adopted the following coding, which we developed specifically for our task: *WHEN* a user (either child or therapist) touches *X-8*, *AND* it produces a reward (according to the current game), *IF* the child looks at the therapist *WITHIN* 3 seconds of the reward *AND* for at least 300 ms, *THEN* this is automatically scored as a JA event (see schema in Fig. 3). This schema allows us to detect the JA behaviour where the child, after *X-8* produced a reward, *presumably* wants to share his experience with the therapist – generally with happiness or surprise –, a behaviour also referred to as *Social Referencing*[4]. The temporal parameters, chosen in collaboration with the therapist who ran the test, are comparable to those suggested in [5]. As shown in Table 3, S_{au} performs JA with a frequency approximately three times lower than S_{cd} (see λ values for comparison).

We also show that it is possible to augment the granularity of the analysis, and examine what happens within a specific *Game*. For example, Table 4 shows data concerning *Game 3*, an activity where *X-8* triggers a reward only if the turn-taking rules are observed. The table compares the twin's performances and provides the following information: for S_{cd}, *X-8* triggered 17 rewards, meaning that child and therapist managed to observe the turn-taking rules 17 times; in doing so, therapist and child touched the toy tentacles 9 and 20 times, respectively, producing 6 episodes of JA. In comparison, S_{au} performed worse: he managed to make *X-8* glow 9 times, although he touched the toy tentacles more frequently (36 touches detected); additionally, only one episode of JA was scored by the script. These results reflect S_{au}'s behaviour in *Game 3*, where he seemed to pay more attention to the toy (evidenced by increased motor activity), but with apparently less understanding of the turn-taking rules.

To conclude, it is also important to note that the for all recorded events (e.g., JA, rewards, users' touches, etc.), the *Platform Log* provides the exact timing of each occurrence (data not shown here due to space reasons). This means that the operator who wants double check the analysis results, can (if the session is video recorded),

Performance in Game 3, S_{cd} vs S_{au}						
Subject	Game duration	No. of rewards	No. of child's touches	No. of therapist's touches	Eye contact	No. of JA
S_{cd}	127.3 sec	17 ($\lambda = 8.01$)	20 ($\lambda = 9.43$)	9 ($\lambda = 4.24$)	7.95 sec (6.2%)	6 ($\lambda = 2.83$)
S_{au}	152.5 sec	9 ($\lambda = 3.54$)	36 ($\lambda = 14.16$)	9 ($\lambda = 3.54$)	5.8 (3.8 %)	1 ($\lambda = 0.39$)

Table 4: For *Game 3*, the table reports the participants' information about: game duration; number of rewards triggered by *X-8*; number of touches on the toy by child and therapist; duration of eye contact; number of JA episodes.

upload the video clip in a standard video editing software[8], set the frame rate to 20 Fps (which corresponds to the sampling frequency of the platform), and locate the event of interest. For example, the first JA event of S_{cd} during *Game 3* (see Table 4) is detected at 3:33:18 (timecode: min, sec, frames), the second at 3:43:16 and so on.

4 Conclusion and Future Work

In this WiP we showed how the preliminary analysis of data collected by the platform, already provides interesting information about the play and attentional dynamics between child and therapist. The tables discussed above are just examples of the type of analysis that can be conducted.

While all the presented data are objective (e.g., touch sensors activations, timing of rewards, etc.), we are aware that the coding schema we implemented to detect JA events is specific to the particular task with *X-8*, and that the temporal parameters used to score an event as JA are arbitrary, although inspired to the values found in [5]. Nevertheless, we believe this is a reasonable approximation of the attentional behaviour under consideration; the schema was also approved by the experienced therapist, who conducted the test. It is important to note, however, that the timing values we used to detect JA are just parameters in the script, which can be refined in future tests; this can be achieved by collecting additional data from other participants and involving more therapists to assess the "goodness" of the parameters themselves.

As a next step, we plan to organise a new test involving a larger number of both neurodivergent and neurotypical participants, to build an initial reference database, potentially useful for treatment, monitoring and even early screening of NDD. Additionally, we will refine the analysis script to extract further information – currently not considered – about the play and social dynamics between child and therapist.

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[8]We used Kdenlive, a free and open source video editor software.

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