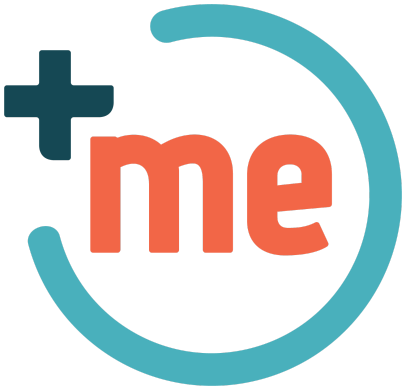
www.plusme-h2020.eu



PlusMe: Transitional Wearable Companions for the therapy with children with Autism Spectrum Disorders

a European funded project

Deliverable 4.1

Final project report

Work Package 4 *Management*
due at month 21 (31th May 2022).

Lead beneficiary: CNR
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Project coordinator National Research Council of Italy,
Institute of Cognitive Sciences and Technologies, ISTC-CNR.

1. Overview of the deliverable

This conclusive deliverable gives a general overview about the project scientific and technological outcomes and the related activities, and reports a summary of all project deliverables[1]. This document is divided into 3 main sections as follow:

- **section 1, engineering activities**. This section reports the technical details about the novel, engineered version of the panda *PlusMe,* the *Transitional Wearable Companion* (TWC) interactive toy – main technological outcome of the project – designed to support the early therapy of children diagnosed with Autism Spectrum Disorders (ASD). Additionally, a brief description of the octopus *X-8* – a new TWC designed to support *turn-taking* games in ASD – is also reported;
- **section 2, experimental activities**. This section reports a summary about the clinical results obtained during the experimentation of *PlusMe* with ASD children in the course of the project;
- **section 3, dissemination activities**. This section reports the activities carried on to disseminate the project results, including publications of scientific papers, participation in conferences or events, organisations of workshops.

All these results are described in more detail in the project website www.plusme-h2020.eu.

It is also important to note that several activities will continue also after the end of project, supported by the related European project *IM-TWIN: from Intrinsic Motivations to Transitional Wearable INtelligent companions for autism spectrum disorder*[2], where *PlusMe* device is used as a component of a wider technological system.

1. Engineering activities

During the project, ISTC-CNR collaborated with the *Institutes for Microelectronics and Microsystems*, IMM-CNR[3], a research institute part of the National Research Council of Italy (CNR, the same legal entity of the project coordinator ISTC-CNR), to produce an engineered version of *PlusMe* interactive toy. This new toy prototype presents novel hardware and software features, which improve the main functionality of the device[4].

[1] The project public deliverables are available at www.plusme-h2020.eu/deliverables/
[2] https://im-twin.eu/
[3] www.imm.cnr.it/ and www.plusme-h2020.eu/coordinator/; see also deliverable D1.1 *Identification of a research partner for engineering PlusMe*.
[4] See deliverables D1.2 *Engineering process of PlusMe*, D1.3 Product demonstrator, D1.4 *Final report on PlusMe device*.

1.1 New hardware and new design

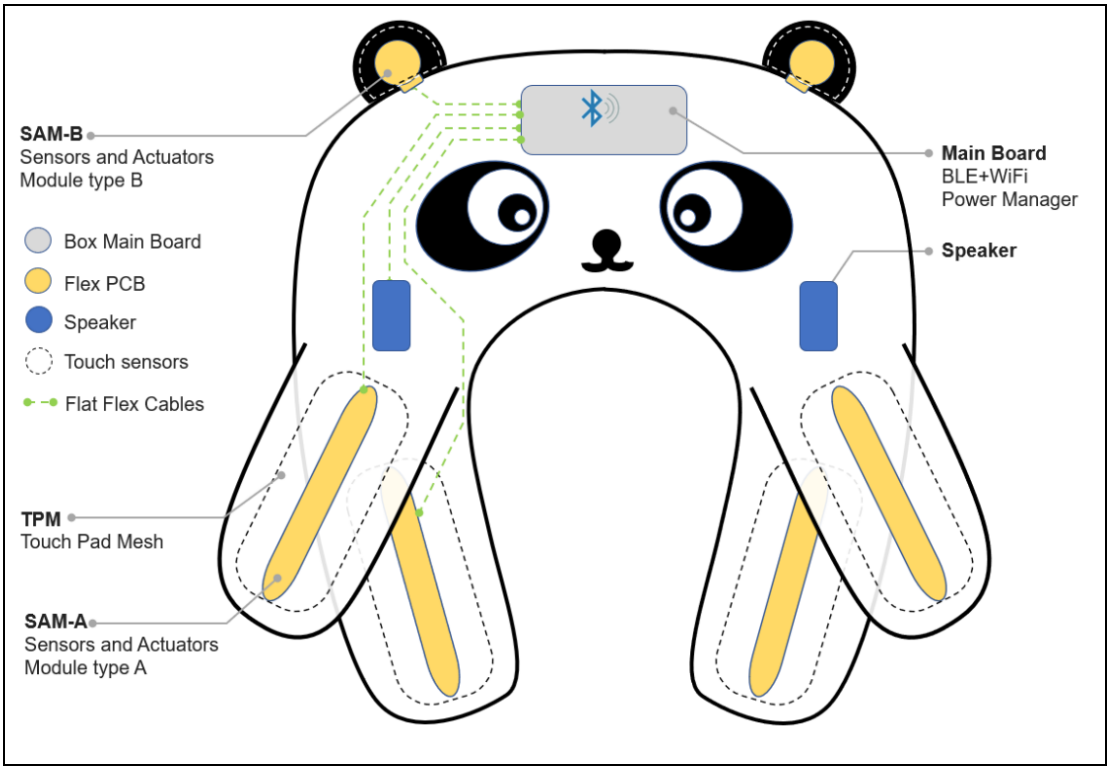

Figure 1. The simplified logic architecture of the new *PlusMe* device. Sensors and actuators are hosted in customised flexible PCB (SAM-A and SAM-B modules in the figure), embedded in the panda paws and ears.

IMM-CNR developed a customised hardware for *PlusMe*, including a miniaturised Printed Circuit Board (PCB) and new electronics hosting improved actuators and sensors (fig. 1 and 2). The advanced device is characterised by the following technical features:

- **Inputs.** The human touch is detected by conductive patches, sewn underneath the external cotton fabric (the "Touch Pad Mesh, TPM" in fig. 1). The patches, as shown in figure 3, are invisible and do not interfere with the light diffusion. The touch sensitive areas are placed on the 4 paws, the two ears, and the panda head;

- **Outputs**. The device is equipped with 3 types of outputs, to produce different sensory feedback for the user:

    - **visual feedback**. IMM-CNR developed 4 customised strips of addressable LEDs, which are embedded within the soft padding of the 4 paws (fig. 2 and 3);
    - **auditory feedback**. 2 mini-speakers are embedded within the Panda head;
    - **haptic feedback**. 6 vibrating motor mini-discs are embedded within the 4 paws and the 2 ears;

- **Printed Circuit Board.** IMM-CNR developed a PCB hosting the main electronics (fig. 2 left). The Main Board is based on ESP32, a microcontroller equipped with Bluetooth and WiFi connection, which easily integrates with the Arduino IDE[5] programming interface. The PCB, powered with a 7.4 V Lipo battery, is inserted and protected by a 3D printed custom box (fig. 2, right).

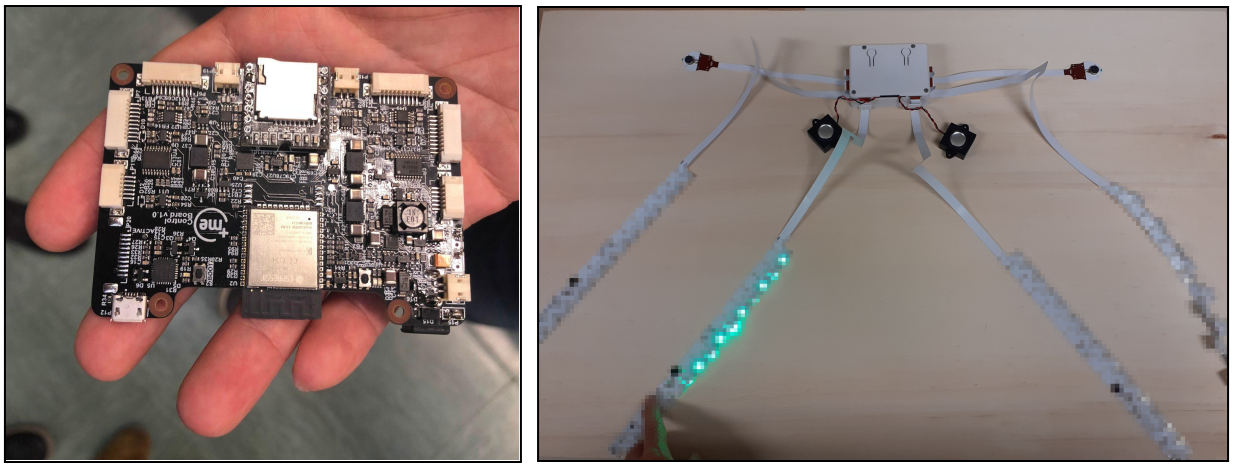

Figure 2. Left: the Printed Circuit Board (PCB) hosting the main electronics. Right: the complete electronics, including the PCB (protected within a 3D printed box), the mini speakers, and the flexible strips hosting the LEDs and the sensors (SAM-A and SAM-B modules in fig. 1).

Importantly, the engineering process of electronics was carried out with industrial criteria (i.e., through the use of standard schematics and electronic diagrams; production of standard blueprints, etc.), in order to obtain a potential "product", ready for a scale production[6].

The final effect of the new hardware is emphasised by the improved *PlusMe* design features: the novel prototype was in fact realised by a professional tailor, expert in the manufacture of soft teddy bears. For this purpose, a new textile – a mix of cotton and 10% elastane, certified *Standard 100 by Oeko-Tex*®[7] for safe use with children – was also used; this textile is characterised by softness and elasticity, pleasing to human touch and more adapt for a soft toy. Interestingly, the flannel fabric texture nicely improves the diffusion of the LEDs coloured lights, an aesthetic feature very important for the final *PlusMe* design (fig. 3).

[5] https://www.arduino.cc/en/software
[6] A small scale production is planned in the project IM-TWIN, see deliverables 3.5 and 3.6 *PlusMe production one* and *two,* https://im-twin.eu/deliverables/
[7] www.oeko-tex.com/en/our-standards/standard-100-by-oeko-tex

Figure 3. During the project *PlusMe* was partially redesigned as a more friendly, attractive outlook. The images show some examples of the nice coloured light diffusion.

1.2 New software

ISTC-CNR developed a completely new control software, realised through an Android App developed with *Godot*[8], a free open source 2D and 3D game engine. Interestingly, the ISTC-CNR researchers developed a general, previously missing Android plug-in[9], which enables a Godot-based App to connect and communicate with one or more Bluetooth Low Energy devices. The App GUI[10] was designed to be user-friendly, as it will be addressed mainly to neurodevelopmental therapists (fig. 4 and 5).

Through intuitive buttons and sliders the end user (e.g., a therapist) can easily manage the *PlusMe* behaviour and configure the operating mode; for instance, he/she can select the desired toy function (namely the “game” to play with the child), and/or configure the general aspect of the toy (e.g., the colour or sound that the toy produces when the child’s touch is detected).

[8] https://godotengine.org/
[9] The code is freely available at https://github.com/IM-TWIN/BLE-Android-Plugin
[10] Graphical User Interface

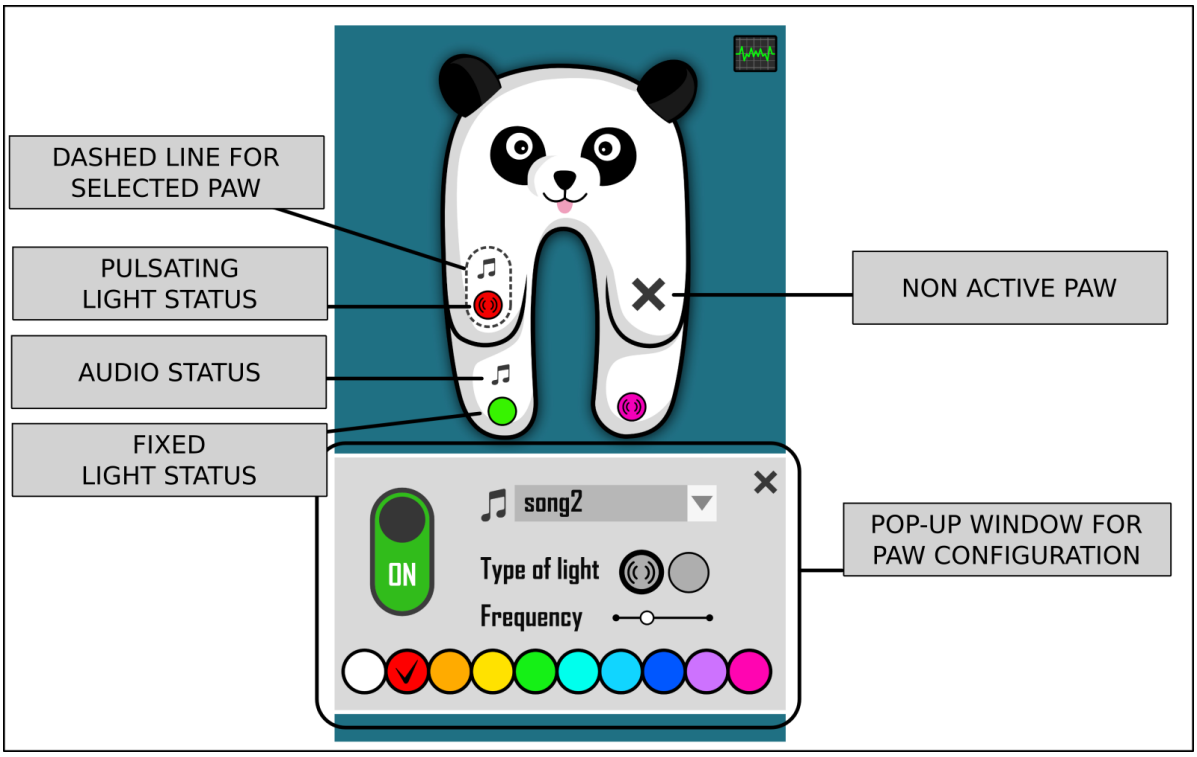

Figure 4. Top: the new control App, through an intuitive GUI, allows the user (a therapist or a caregiver) to customise several *PlusMe* features: for example he/she can select the colour of the light, its temporal pattern (steady or pulsating) and the sound to be emitted when *PlusMe* detects a touch. Bottom: examples of *PlusMe* different configurations.

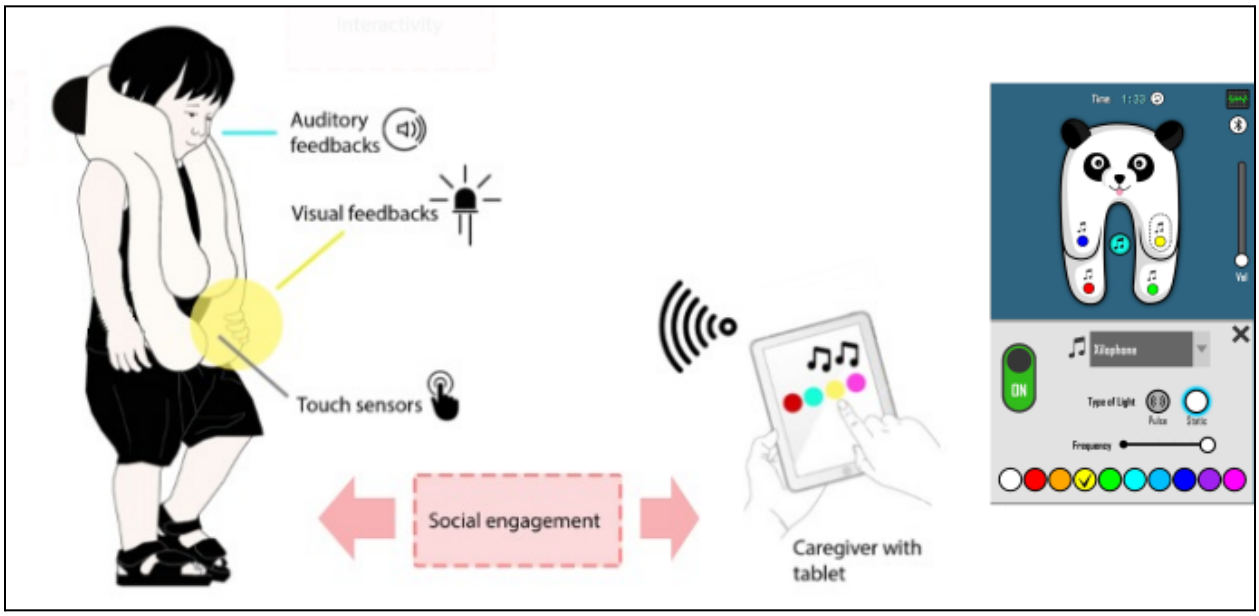

Figure 5. Through the new App, the end user can manage the various *PlusMe* features (visual, auditory, haptic feedback), selecting the most appropriate sensory outcomes, according to the child's behaviour and preferences.

Several videos showing the new *PlusMe* device and the control App are available at the dedicated project page www.plusme-h2020.eu/video/.

1.3 The octopus *X-8*: a new *Transitional Wearable Companion*

One of the additional outcomes of *PlusMe* engineering process is the development of an another interactive toy called *X-8*[11] (fig. 6 and 7), which relies on an improved version of the *PlusMe* hardware and software. The octopus *X-8* is able to distinguish between two users' touch (child and therapist), and to respond accordingly producing different lights and sounds. This TWC was specifically designed to support *turn-taking* games in ASD children, namely play activities where it is required to alternate a behaviour, a social competence often impaired in ASD. The clinical test on ASD children, to assess the effectiveness of *X-8*, is planned for October 2022.

Thanks to the connectivity offered by the ESP32 microcontroller, *X-8* will be also able to connect to *PlusMe*, to create a more complex system composed of interacting toys. This technical feature could potentially enhance the effectiveness of TWC devices, improving the interactivity and the complexity of the whole system, and possibly stimulating even more the social engagement of children.

[11] Video available at www.plusme-h2020.eu/video/#the_octopus_x_8

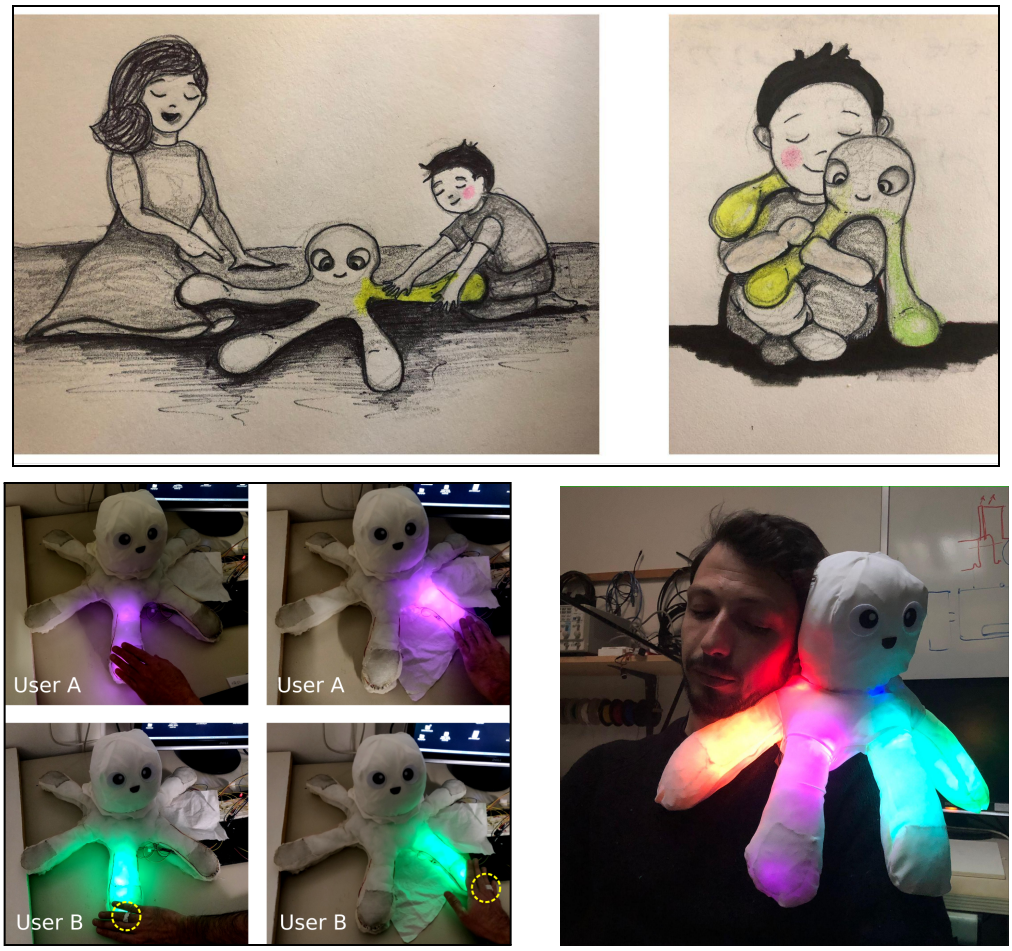

Figure 6. Top: design concept of *X-8*, the new TWC to support *turn-taking* games. Bottom: the toy (early prototype) is able to distinguish between two users' touch (user A and B in the pictures), producing different colours.

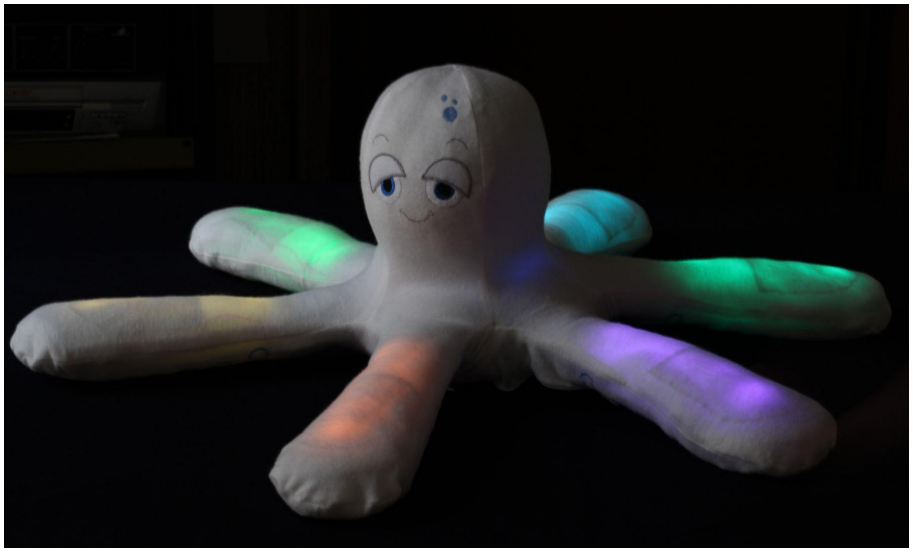

Figure 7. The final prototype of the octopus shaped toy *X-8*.

2. Experimental activities

During the project, the *PlusMe* device was used in a pilot experiment involving 9 children diagnosed with high functioning ASD, aged between 36 and 53 months. The experiment was carried out in collaboration with the researchers from the Department of Human Neuroscience, Section of Child and Adolescent Neuropsychiatry, University of Rome *LaSapienza*[12].

The test consisted in a 10 minutes long play activity (fig. 8 and 9), involving the child and the therapist mediated by the panda, and repeated for 4 sessions (once per week). The preliminary results, where the toy was used to stimulate the child's social engagement, showed a promising improvement during the 4 sessions of some key social indexes, often impaired or atypical in the most of ASD subjects. For example, the quantitative data shows a moderate increment of the eye-contact behaviour between child and therapist (fig. 10), along with the social smiles (namely the child's smiles toward the therapist), the imitative gestures (where the child first observes how the therapist interacts with the toy, and then repeats the behaviour), and the number of social requests made by the child to therapist to manage the *PlusMe* aspect (fig. 11);

Qualitative feedback from the therapist involved in the experimentation, reports how the *PlusMe* toy seems to be effective in capturing the child's attention, in creating dynamics of joint attention and in stimulating the child's social engagement. More details are available in the dedicated clinical deliverables[13]. Moreover, selected clips of the experimental sessions are available at the dedicated project page www.plusme-h2020.eu/video/#ExperimentalSessionMayJune2021.

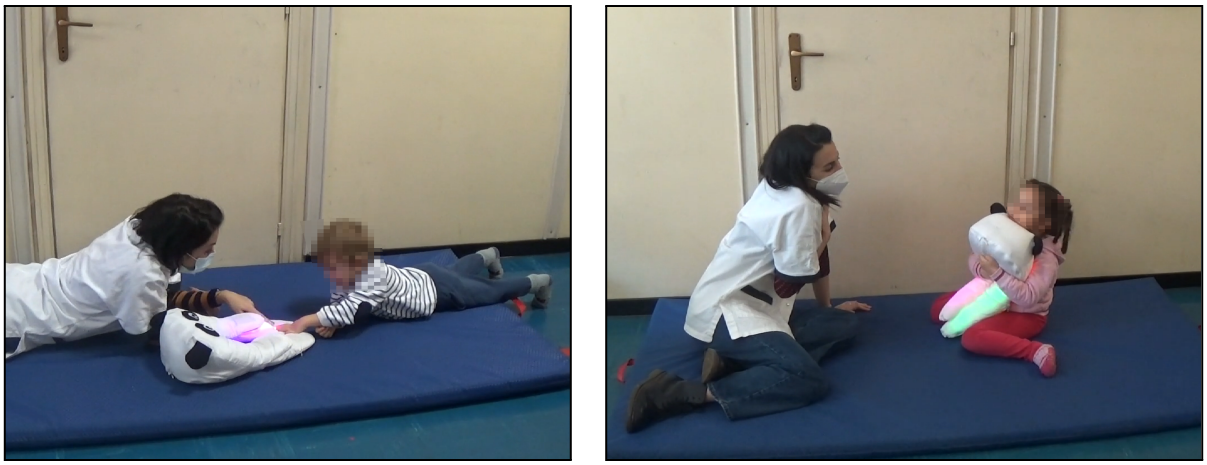

Figure 8. Images selected from the experimental sessions, showing the interaction between child, therapist and *PlusMe*. The control tablet to select the current game is in the hands of a second experimenter (in the same room, not shown in the picture).

[12] www.plusme-h2020.eu/coordinator/
[13] See deliverables D2.1 and D2.2 *Experimental phase, stage one* and *stage two*

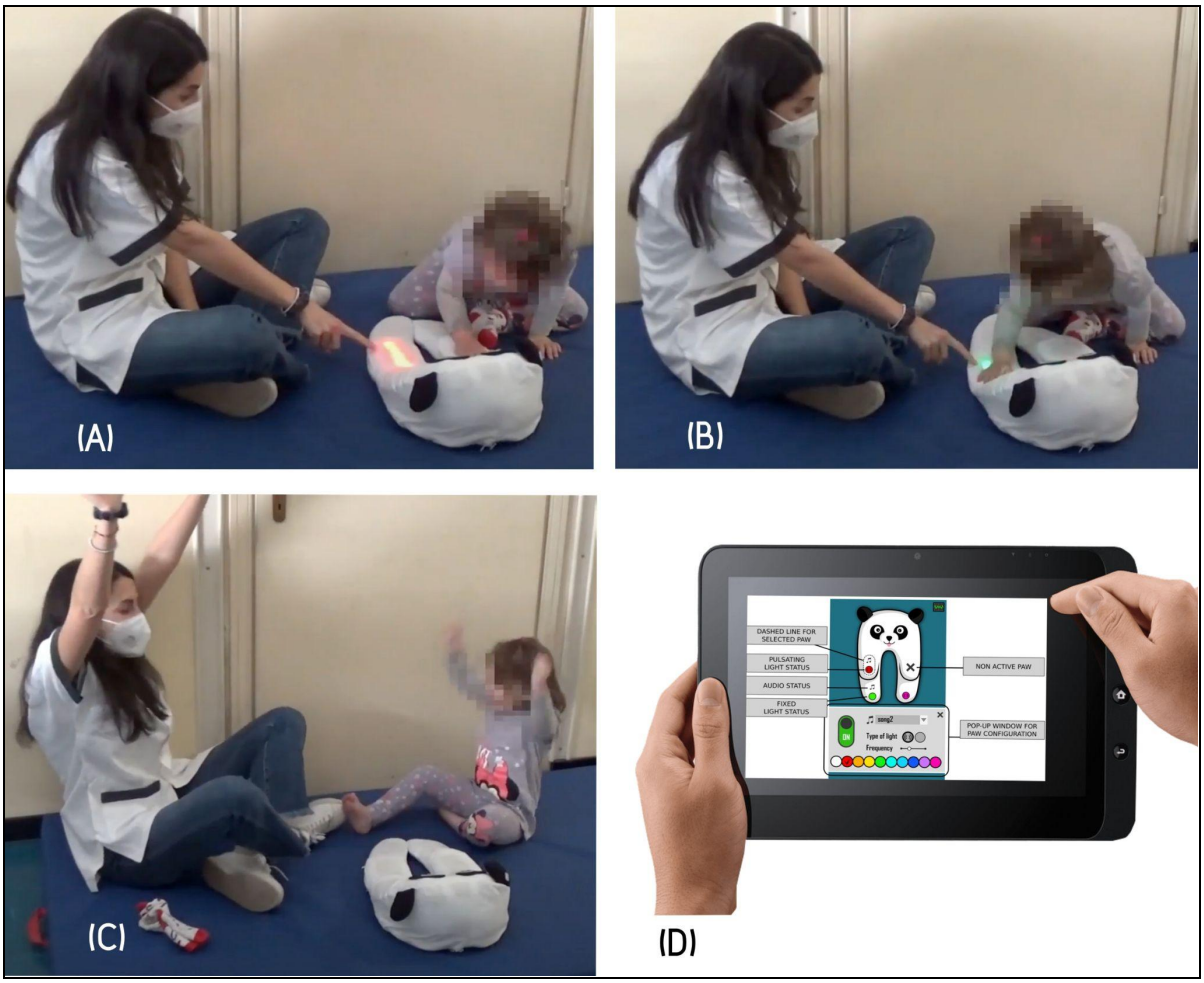

Figure 9. An example of a temporal play sequence: in A) the therapist points to the red blinking panda's paw; in B) the child touches the paw, which responses changing colour to green and emitting a brief song; in C) child and therapist rejoice for the rewarding song and green colour; in D) the control tablet to select the current game, in the hand of a second experimenter (in the same room, not shown in the picture).

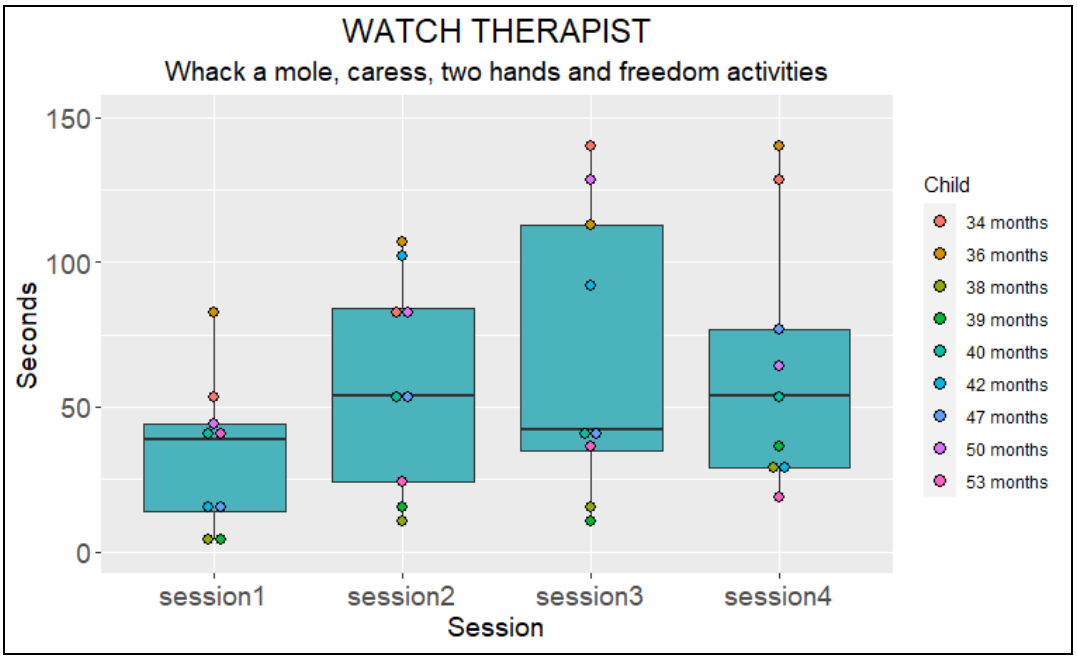

Figure 10. The box plots show a moderate increment, during the 4 sessions, of the eye-contact (*watch therapist* index) behaviour between child and therapist, when playing with *PlusMe*. This behaviour is often impaired in ASD subjects.

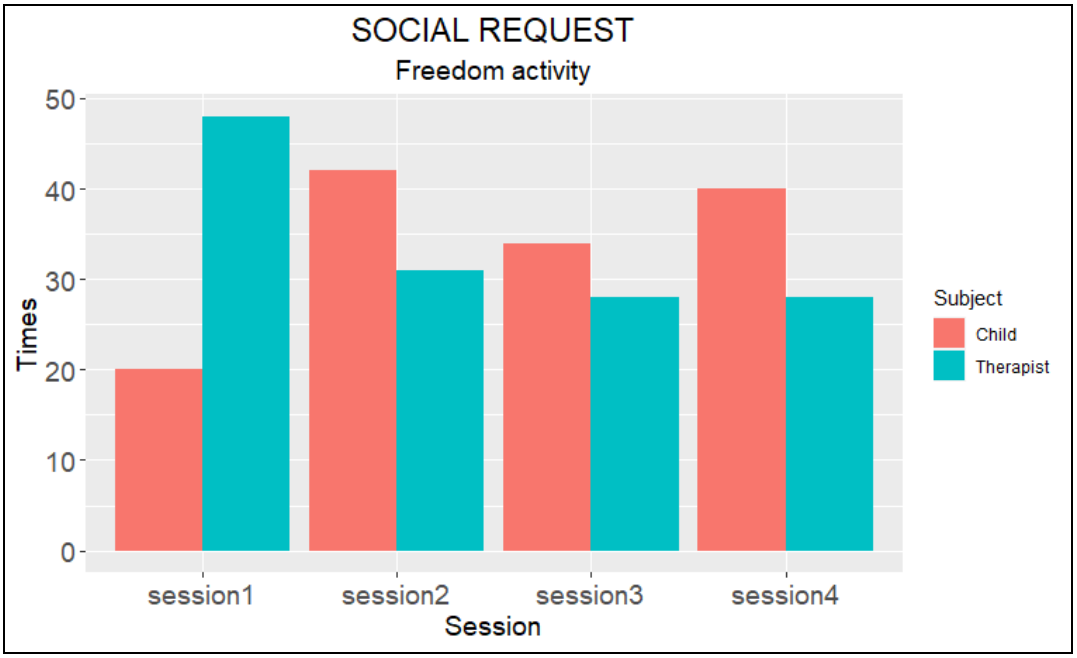

Figure 11. The graph shows how the social interactions (*social request* index), namely the child's requests (orange bar) toward the therapist to manage the *PlusMe* aspect, increase between the 1st and 4th sessions; this is observed during the *freedom activity*, a game where the therapist asks the child his/her preferred toy colour or sound, to be produced when touching the panda paws.

It is important to note that the above clinical trial is currently ongoing and will continue beyond the project, in order to increase the number of participants and strengthen the statistical analysis.

The experimental activities using *PlusMe* (as described in the next section 3.3 *Diffusion of PlusMe to other users*) will also extend to other institutes to obtain important feedback about the potential use of the device, both with ASD and with Typically Developing (TD) children. In particular the *Centre for Research and Interdisciplinarity*[14] (CRI) a French research institute active in the field of developmental psychology, is currently using the toy with TD children, in a pilot experiment to evaluate the toy effectiveness in detecting early warning signals in social behaviour[15], a potential relevant use for the early diagnosis of ASD.

Figure 12. Selected pics showing the experimental activity involving children with typical development, carried out in *Centre for Research and Interdisciplinarity,* a French research institute, active in the field of Developmental Psychology.

3. Dissemination activities

The project outcomes were presented through several activities including: scientific publications; participation in scientific conferences, design events and technology fairs; organisation of dedicated workshops.

Additionally, the ISTC-CNR is providing selected institutes with some samples of *PlusMe* toy, to extend the experimentation of the device with ASD and TD children, and then facilitating the dissemination of the main technological project outcome; this activity is supported by the small scale production of *PlusMe*, planned in the related European project *IM-TWIN: from Intrinsic Motivations to Transitional Wearable INtelligent companions for autism spectrum disorder*[16].

[14] https://learningplanetinstitute.org/en
[15] This research is done in collaboration with the University of Rome *La Sapienza*, within the project IM-TWIN.
[16] See deliverables D3.5 and D3.6 *PlusMe production one* and *two* https://im-twin.eu/deliverables/

3.1 Publications

The scientific results about the project have been published in the following papers[17] and presentations:

- ***X-8: an experimental interactive toy to support turn-taking games in children with Autism Spectrum Disorders*** (2021), B. Özcan, V. Sperati, F. Giocondo, G. Baldassarre. Extended Abstract presented at the *23rd International Conference on Human Computer Interaction, HCI International 2021*, published in *Posters HCII 2021, Communications in Computer and Information Science,* pp. 233-239, vol 1419, Springer, Cham, DOI: 10.1007/978-3-030-78635-9_32

- ***Leveraging curiosity to encourage social interactions in children with Autism Spectrum Disorders*** (2022), F. Giocondo, N. Faedda, G. Cavalli, V. Sperati, B. Özcan, F. Giovannone, C. Sogos, V. Guidetti, G. Baldassarre. Extended Abstract presented at the *International Conference of Human-Computer Interaction CHI 2022*, published in *CHI Conference on Human Factors in Computing Systems Extended Abstract,* Article No. 273, pp. 1-7, DOI: 10.1145/3491101.3519716

- ***Interactive soft toys to support social engagement through sensory-motor plays in early intervention of kids with special needs*** (2022), B. Özcan, V. Sperati, F. Giocondo, M. Schembri, G. Baldassarre. Extended abstract presented at the 21st edition of the international ACM conference *Interaction Design and Children, IDC '22, section Demo & Art Track*, published in the conference proceedings, pp. 625-628, DOI: 10.1145/3501712.3535274

- ***A Novel System Based on a Smart Toy Responding to Child's Facial Expressions: Potential Use in Early Treatment of Autism Spectrum Disorders*** (2022), F. Montedori, F. R. Mattei, B. Özcan, M. Schembri, V. Sperati, G. Baldassarre. Extended Abstract presented at *24th International Conference on Human-Computer Interaction, HCI International 2022*, to appear in the volume *HCII 2022 - Late Breaking Work - Posters, Springer CCIS volumes of the proceedings*.

3.2 Conferences, design events, technology fairs, workshops

The ISTC-CNR team participated in several dissemination activities including: international conferences, workshops, design events, technology market-oriented fairs events.

- ***Online Educa Berlin, OEB '21***. On 1-3 December 2021, the *PlusMe* team participated in the 27th edition of the exhibition *Online Educa Berlin,* OEB[18] (Berlin, Germany). This is an international, market-oriented, cross-sector conference and exhibition on technology

[17] www.plusme-h2020.eu/publications/
[18] www.oeb.global

for the support of learning and training. The team presented the *PlusMe* device to the audience, who could test the toy and ask for information about its use in clinical activities and its technical features.

- ***Human Computer Interaction, CHI '22***. On April 30-May 5 2022, the *PlusMe* team participated in the ACM *International Conference on Human-Computer Interaction, CHI '22*[19] (New Orleans, USA). The team presented the poster *Leveraging curiosity to encourage social interactions in children with Autism Spectrum Disorders* (fig. 13).

- ***Interaction Design and Children, IDC '22***. On June 27-30 2022, the *PlusMe* team participated in the 21st edition of the ACM *Interaction Design and Children, IDC '22* Conference[20] (Braga, Portugal). The team presented a live demo of *PlusMe* and *X-8* interactive toys within the "Demo and Art Installations" track (fig. 14).

- ***Human Computer Interaction, HCI International 2022***. On June 26-July 1 the team participated in the *24th International Conference on Human-Computer Interaction, HCI International 2022*[21] (virtual edition). The team presented the poster *A Novel System Based on a Smart Toy Responding to Child's Facial Expressions: Potential Use in Early Treatment of Autism Spectrum Disorders*.

- ***Milan Design Week 2022***. This is an important design exhibition hosted within the *Salone Internazionale del Mobile*[22], held in Milan on 6-12 June 2022. The participation was directly linked to the *Honourable Mention*[23] award, won by *PlusMe* interactive toy at *Design Intelligence Award-DIA*[24] contest, edition 2021 (fig. 15). DIA is the first international academic award in industrial design, established in 2015 by the *China Academy of Art*; the contest was created "to celebrate innovators and entrepreneurs' imagination and inventiveness".

- **ICCHP-AAATE 2022**. On July 14 the team participated in the *Joint International Conference on Digital Inclusion, Assistive Technology & Accessibility*, ICCHP-AAATE 2022[25] (Lecco, Italy). The team presented the poster *PlusMe: a Transitional Wearable Companion as a support tool to encourage social-emotional engagement in children with Autism Spectrum Disorders during early therapy,* and prepared a live demo for the audience (fig. 16).

[19] https://chi2022.acm.org/
[20] https://idc.acm.org/2022/
[21] https://2022.hci.international/
[22] Milan Furniture Fair, www.salonemilano.it/en
[23] https://en.di-award.org/collections.html
[24] https://en.di-award.org/about.html
[25] https://icchp-aaate.org/

- ***Maker Faire, 10th European edition***[26]. The team will participate in this important technology exhibition, to be held in Rome on 7-9 October. During the event the *PlusMe* and *X-8* interactive toys will be presented to the audience through live demos.

- ***Workshop at Sapienza University of Rome La Sapienza***. A workshop about the *PlusMe* device and the related experimental activities was organised by CNR-ISTC, in collaboration with the University of Rome *La Sapienza*. The workshop, entitles *PlusMe: il dispositivo sperimentale per il disturbo dello spettro autistico,* was held in Rome on July 16 2021, at the Department of Human Neuroscience, Section of Child and Adolescent Neuropsychiatry[27]. The workshop was attended by approximately 20 people between neurodevelopmental therapists and trainees.

- ***Virtual Workshop***. A virtual workshop entitled called *PlusMe: il dispositivo sperimentale per il disturbo dello spettro autistico* about the *PlusMe* device and the related experimental activities was held virtually on March 28 2022[28]. The workshop, organised online due the COVID-19 restrictions, was attended by 8 people between neurodevelopmental therapists and researchers from research centres, rehabilitation centres, associations, active in the ASD treatment and support.

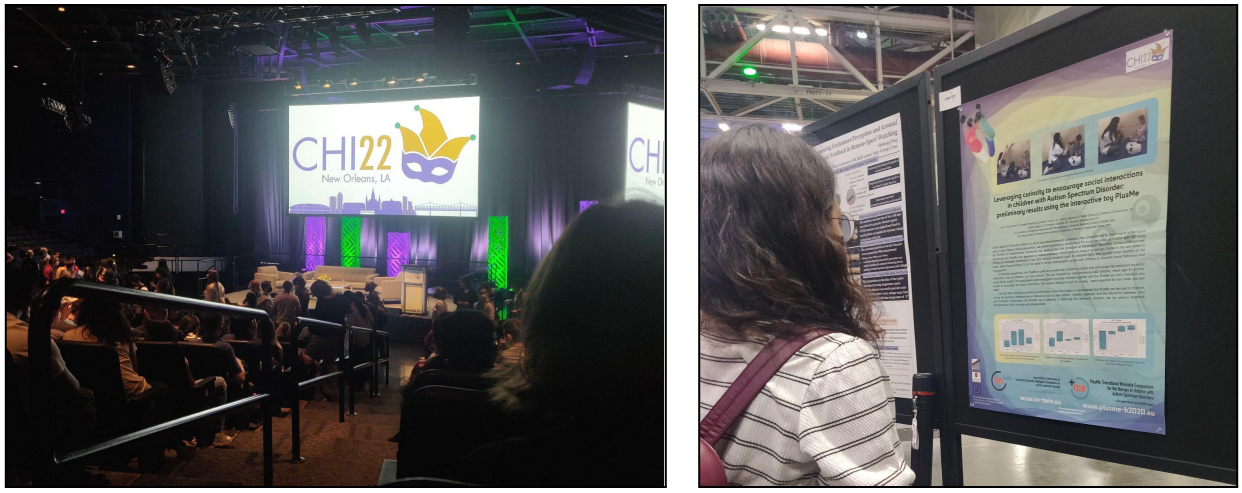

Figure 13. Images of the CHI '22 conference, where the *PlusMe* team presented a poster.

[26] https://makerfairerome.eu/en
[27] See deliverable D3.3 *Dissemination of research activities, stage 1*, www.plusme-h2020.eu/deliverables/
[28] See deliverable D3.4 *Dissemination of research activities, stage 2*, www.plusme-h2020.eu/deliverables/

Figure 14. Images of the IDC '22 conference and the *PlusMe* live demo, where the audience could test the *PlusMe and X-8* prototypes.

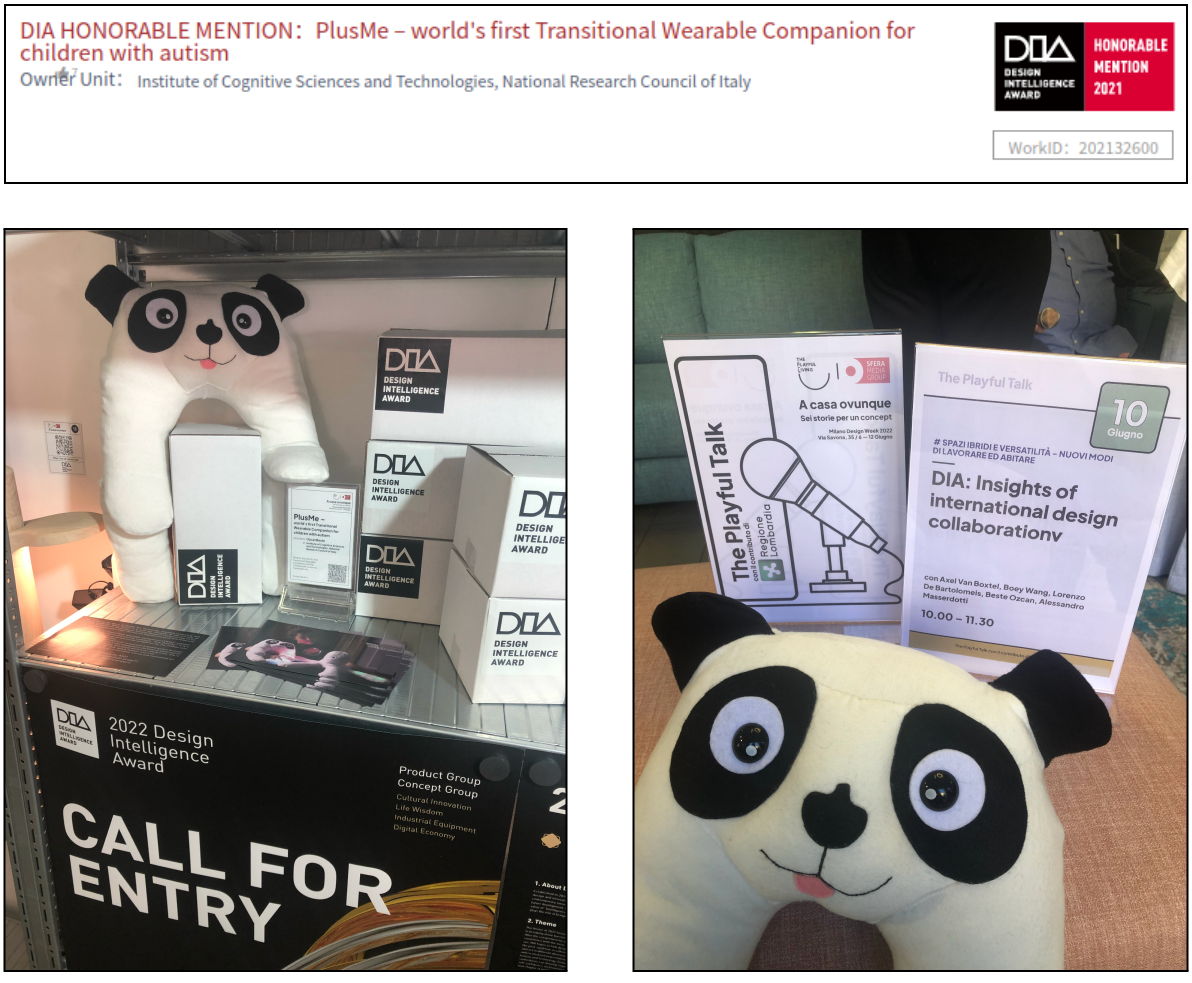

Figure 15. Top: the *PlusMe* got the *Honourable mention* at the *Design Intelligent Award*, DIA contest, 2021 edition. Bottom: thanks to the award, *PlusMe* was presented at the *Milan Design Week* 2022.


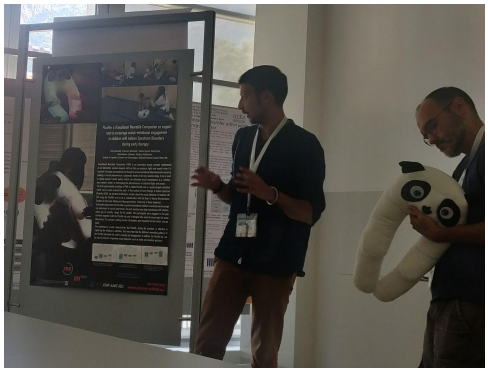

Figure 16. Images of the ICCHP-AAATE conference and the *PlusMe* poster presentation with live demo.

3.3 Diffusion of *PlusMe* to other users

The ISTC-CNR, through the arrangement of scientific collaborations, is providing *PlusMe* to institutes interested in using the device with both ASD and TD children. Here follows a list of the centres formally involved in this extended test, at the date of July 2022[29].

- **University of Rome *La Sapienza***. The Department of Human Neuroscience[30], Section of Child and Adolescent Neuropsychiatry is currently using *PlusMe* with ASD children, to evaluate the effectiveness of the toy as a support tool in therapy. The Department was involved in the experimental activity from the very beginning of the project. Moreover, the Department became also a formal partner of the related European project IM-TWIN[31].

- **Centre for Research and Interdisciplinarity, CRI**. This French research centre, active in the field of developmental psychology, is currently using *PlusMe* with TD children in a pilot experiment within the related European project IM-TWIN[32]. In this scoping study CRI is evaluating, in collaboration with the University of Rome *La Sapienza*, the effectiveness of the toy in detecting early warning signals in social behaviour, a potential relevant use for early diagnosis of ASD.

- **Rehabilitation centre *NeapoliSanit***. *NeapoliSanit s.r.l.*[33] is an Italian rehabilitation centre, specialised in the treatment of physical-psychical and motor deficits, with particular reference to ASD. The research activities focused on *PlusMe* are scheduled to begin from September/October 2022, and will help to evaluate the effectiveness of the toy as a support tool for ASD, as well as for other neurodevelopmental disorders.

[29] See deliverable D2.3 *Diffusion of PlusMe* to other users
[30] https://web.uniroma1.it/neuroscienze/home
[31] https://im-twin.eu/partners/
[32] https://im-twin.eu/partners/
[33] https://neapolisanit.com/mission/

- **Association *Italiacamp***. *Italiacamp* s.r.l.[34] is an Italian association which promotes activities with social impact. The association carries on several educational projects involving TD children, focused on social inclusion, use of innovative tools and learning models. The research activities based on *PlusMe* are scheduled to begin from September/October 2022, and will help to evaluate the effectiveness of the toy as a support tool for TD children, to develop the *emotional intelligence* through social games (namely play activities where the children learn to understand the emotional state of each other).

5. Conclusions

Although the project *PlusMe* has formally ended, several activities will continue, supported by other related research projects. In particular, the project IM-TWIN is currently supporting the clinical trials with ASD and TD children, and the further hardware and software development of *PlusMe* device[35].

The *PlusMe* team wishes to thank the researchers who strongly contributed to the project activities[36], in particular: Dr. A. Pecora, Dr. M. De Luca, Dr. P. Sperandio from IMM-CNR, for their help in developing the novel *PlusMe* hardware and electronics; Prof. Guidetti V., Dr. Sogos C., Dr. Giovannone F., Dr. Faedda N., Dr. Cavalli G. from the Department of Human Neuroscience, Section of Child and Adolescent Neuropsychiatry, University of Rome *LaSapienza*, for their help and support in the experimentation of *PlusMe* toy with ASD children.

Figure 17. The panda *PlusMe* and the octopus *X-8 are* the main technological outcomes of the project.

[34] https://italiacamp.com/it/
[35] See for example deliverable D3.3 *PlusMe augmented behaviour*, https://im-twin.eu/deliverables/ where *Computer Vision* is used to enhance the toy interactivity.
[36] www.plusme-h2020.eu/people/