D4.2
Proof-of-concept testing and validation in healing and everyday life support of disabled – Phase 2

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[1]**PU** = Public, **PP** = Restricted to other programme participants (including the Commission Services), **RE** = Restricted to a group specified by the consortium (including the Commission Services), **CO** = Confidential, only for members of the consortium (including the Commission Services).

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Abbreviations

IMS	Individual Motor Signature
GMS	Group Motor Signature
IMU	Inertia Measurement Unit
MoCap	Motion Capture
WP	Work Package

1 Introduction

This deliverable provides an update of deliverable D4.1, focusing on the work done in the third year of EnTimeMent in the design and development of our proof-of-concept for Scenario 1. The main objective is to perform evaluations in ecological settings of some of the scientific results obtained in the project.

Main research questions include the following:

How can multi-time EnTimeMent technologies improve early diagnoses and support re-habilitation and functioning in everyday life in children with disability ?

How multi-time EnTimeMent technologies can contribute to the design of embodied education and edutainment experiences both in typically developed children and with disability?

How can multiple temporal scales support the evaluation of the quality of interaction in the dyad child-caregiver? When and how a dyad becomes a single organism (e.g multi-scale synchronization of head movements, body sway and forearms)?

How multi-time interactive sonification of individual movement and joint action can improve the quality of interaction, synchronization and entrainment in the dyad?

Do clinical and psychological standard evaluation and coding systems for individual functioning and interaction (see D4.10) correlate with automated computational measures of multi-scale synchronization, entrainment and functioning?

Scenario 1 focuses on individual and interactive functioning (with mother or therapist) of typical developed children and with disability in daily life. The aim is (i) to support clinicians and therapists in early detection and rehabilitation of disabling condition,(ii) to enable children and caregivers in better functioning, (iii) to support education personnel in embodied education and edutainment experiences for both healthy and impaired children. In this directions, Scenario 1 explores ecologically valid contexts for the exploitation of some of the results obtained in WP1, WP2, and WP3.

Phase 2

The persisting Covid-19 pandemic limited the planned collaborative tasks with the Children Hospital Gaslini. In particular, also in this Phase 2 we could not access the hospital for experiments. As in phase 1, we did experimental work inviting children and caregivers the Casa Paganini-InfoMus premises. In particular, we did recordings of the selected experimental setups during the Markerless Motion Capture Campaign, in November 2022. The main activities in this second phase are the following: (i) refinement and definition of the experimental setup, including further analysis of the CID for validation and evaluation, (ii) markerless recordings at the Markerless Motion Capture Campaign in Genoa (November 2022).

2 The Target Group

The main targets are children with cognitive and/or motor impairment, and theircaregivers.

In particular, we focus on experiences in which child moves spontaneously and others in which he interacts with caregiver and/or therapist in a daily activity for reactivation or rehabilitation. The typical case is based on dyad formed by child and mother or another caregiver in joint (cooperative) activities .

We aim at identifying and studying situations characterized as follows:

- Multiple temporal scales clearly emergent and measurable,
- A dialog (interaction) is present between a child and a caregiver/therapist, in terms of synchronization, entrainment, alternation, pauses, reciprocal adjustment dynamics in a well-balanced partnership and leader-follower situations,
- Full-body physical interaction and multisensory non-verbal multimodal stimulation are the main channels, including interactive sonification.

This scenario includes situations characterized by

- low or reduced verbal communication skills
- limited spatial displacement, e.g., in a standard room,
- high inter-dependency between the child and the caregiver, i.e., dyads characterized by natural, and possibly necessary, interaction to perform joint actions.

From the above requirements, and from an in-depth investigation of other requirements from the hospital clinical personnel, this scenario potentially includes the following age-range categories:

1. 0-4 months
2. 6-9 months (pre-verbal age)
3. 2- 5 years-old (pre-scholar age)
4. 8–11 years old

Typically developed children are considered as reference control groups for children with disability.

3 Daily Life Environment and the "InHospital Smart Home"

The daily life environment of the child and his family ideally represents the experimental setting. In case of sick or child with disability the hospital environment becomes a transitory environment of the child's life until he returns home. To improve the continuity of care and support the discharge of children with complex rehabilitation needs, the Gaslini Hospital created an "in-hospital smart home". It has been conceived as a transition "smart ecological environment" where the child with medical complexity and his family can live and check, for a short time (7-14 days), their autonomy and safety. During the stay in the "In-Hospital Smart Home", the child is monitored and supported by smart technologies, and the amount and frequency of medical or assistive help needed is recorded. Clinical and functional data are collected for analysis from hospital admission up to hospital discharge and after, in case of prosecution of care.

4. Narrative Structure and Activities

In a setting represented by the child daily life environment, the time reference is the child's day.

The day is marked by activities and the activities are in turn divided into actions and interactions conceived as task-oriented meaningful short segments of activity.

The child's day is characterized by typical activities for his/her age with the addition of specific care activities. In the Use Case of Giorgio (4 years old), he wakes up in the morning and his mother assists him in small personal care tasks and in breakfast. Then she accompanies him to the rehabilitation therapy session and after to the kindergarten. In the periods he does not go to school, after therapy session, he spends the morning at home with his mother, dedicating himself to recreational and educational activities. At the end of the morning Giorgio prepares for lunch, which he completes sitting at the table always assisted by his mother or assistant. At the end of the lunch he makes a short afternoon rest. After the rest his day continues with a new rehabilitation therapy session, a snack and before dinner another space for playful-didactic activities. After dinner preparatory activities take place for the night's rest which is facilitated by a quiet activity such as telling/reading a fairy tale.

For study purpose, we can divide the activities of Giorgio daily life as well as of a typically developing child of the same age into five main activities:

a) Recreational and educational activities
b) Feeding activities
c) Personal care activities
d) Rest/sleep activities
e) Specific care assistance activities

The rehabilitation activity is not included in the specific care activities because, in case of severe disability, the rehabilitation activity becomes a life project and accompany the child in his daily life.

In Scenario 1, to be considered a first phase of experimentation, we will consider as object of study only a) and b) activities: recreational and educational, and feeding activities.

To complete the scenario, the possibility of inserting some elements of the three activities excluded in this phase will be evaluated: they might be included in the preparatory, intermediate or final phase of the two "activities" under study.

Activities should be independent. Nevertheless, when useful or necessary, they will be assisted by the parent or by the therapist or by the teacher.

Physical and virtual objects and tools can be included as component of the environment of the experience: they will be chosen or developed as parts of the interaction design process, aiming at facilitating the effective implementation and evaluation of the designed cooperative/interactive activities, including cases of low-level functioning

The activities are divided into actions and interactions conceived as task oriented meaningful short segments of activity.

The actions and interactions with their multiple components are the main object of the study.

Three different examples of activities with relatives action/interactions and references to the time scale are illustrated in the table below.

Activity	Action/Interaction	Events to study and temporal scale
2-5 years child recreational/educational activity	Sit down on a chair, stay on a chair, stand up from a chair. Playing exchanging or launching an object/ball. Playing together building a construction. Request for, attention in, enthusiasm in, pleasure in interaction/participation. Refusal of, boredom in, frustration in, discomfort in interaction/participation.	Low frequency temporal scale: individual and interpersonal rest and activity rate, interpersonal movement synchronization time, interpersonal coordinate alternance time, interpersonal movement convergence and divergence time Intermediate frequency temporal scale: head, trunk and global limb movements; breath frequency High frequency temporal scale: head and hand movements, heart frequency, emg, skin conductance
2-5 years feeding activity	Sit down on a chair, stay on a chair, stand up from a chair. Demand for food, pleasure for food, disgust for food, refusal of food, offer of food, help for feeding. Pick up a bite from the plate, bring a bite to the mouth, chew and swallow a bite.	Low frequency temporal scale: meal frequency, cough, regurgitation, hiccup, individual and interpersonal rest/activity rate, interpersonal movement synchronization time, interpersonal alternance coordination time, interpersonal movement convergence and divergence time Intermediate frequency temporal scale: trunk,arm, head movements, swallowing, breathing.

	Drinking from a glass, drinking from the bottle. Offer a lollipop, suck a lollipop, suck a dummy.	High frequency temporal scale: chewing, sucking, heart frequency, skin conductance,.
Newborn (0-4 months) spontaneous motor behavior 0-4 months	Sleep and rest, awake, cryng.	Low frequency temporal scale: awake rest/sleep rhythms. Intermediate frequency temporal scale: Global body movements (poor, rich), head movements, general limbs movements (cramped, variate), breath frequency. High frequency temporal scale: fine hands movements (fidgety), heart frequency.

Activities should be appropriate to the age of the subject and scalable for the different levels of functioning (from the "normotypic" subject to the subject with disabilities). Further, they should be also used with rehabilitation goals.

The requirements include the following: activities must be carried out completely within the case study considered; whenever possible, a full-body engagement will be considered, possibly including the use of orthoses, wheelchairs, or other types of aids. Actions should be independent. Nevertheless, when useful or necessary, they will be assisted by the parent or by the therapist or by the teacher.

Physical and virtual objects and tools can be included as component of the environment of the experience: they will be chosen or developed as parts of the interaction design process, aiming at facilitating the effective implementation and evaluation of the designed cooperative/interactive activities, including cases of low-level functioning (e.g. a brush or a musical instruments with handles facilitating the joint action).

4.1 Interactive Sonification of Movement

Real-time interactive sonification of movement qualities and of features related to joint actions can be an important component to both diagnosis and support to the performance of activities.

We propose a multi-time sonification strategy of individual movement qualities and of joint actions features, aimed at (i) stimulating child awareness and improving her movement and behavior in joint actions, and (ii) to support the caregiver in diagnostic or evaluation tasks.

In the following we describe a first hypothesis of the multi-time interactive sonification architecture.

We can individuate three phases: preparation of the activity (e.g., the rituals to smoothly introduce the child to the activity), the core activity, and a post-activity phase. The sonification structure considers an interactive storyboard/narration covering all these three phases, and is structured at two levels:

level A (facilitating proprioception and differentiation of temporal scales at 0.5s- 2-3s):

Sonification augments the qualitative perception of the caregiver/child unit's movements. For example, sonification can map smooth movements with fluid sounds, energetic movements with similar sonic energies, light and suspended movements with sounds which evoke lack of weight. The approach follows the multi-layered movement analysis model described in (Camurri et al 2016), and starts from the cross-modal correspondences at different temporal scales between movement qualities and spectral features we recently developed (Alborno et al 2016; Niewiadomski et al 2019).

Synthetic sound environments such as those adopted in (Niewiadomski et al 2019) are not considered here. To facilitate immersion and engagement, we propose a multi-layered sonic environment based on real and naturalistic sounds and musical elements, grounded on cross-modal correspondences between movement and sonic time-spectral analysis.

level B (facilitating communication from the child to the care-giver, at slower temporal scales at >=10s)

Level B observes the overall context of the individual and joint actions. For example, sonification should help the caregiver to understand phases in the child's cycles of fatigue / attention, during the session. In general, the role of level B is to modulate, activate and disactivate the sonifications emerging from Level A. For example, the movement sonification (level A) can become sharp and vivid Vs. blurred and hazy, to inform the caregiver about the attention state of the child (synchronized and engaged

Vs. non-cooperating and distracted). The modifications of such sounds may depend on the analysis of child's synchronization or coordination with the caregiver, measured on a very slow temporal scale.

The persistence of a movement and behaviour context (detected at Level B) may cause the system to reshape or to change the sonic mapping. If the analysis of slow trends in attention and engagement show that the child is lacking interest in the experience, new Level A sonifications of different movement features following a modified interactive narrative structure might emerge, to stimulate curiosity and bring back the child to the centre of the activity.

A naturalistic-like soundscape supports the relaxing preparatory phase before the beginning of the session, animated by subtle sonic background (i.e. sounds of birds with density and movement varying in space and time).

The sonification can support the caregiver: for example, the same sound can become more and more calm and static, to signal to the care-giver that the child is tired and needs rest.

The observation of the interaction at different temporal scales provides further information:

1) relevance of movements, to drive the moments and movement features mapped to sonic material, in order to filter out redundant, involuntary, and not intentional movements, and to give relevance to movement qualities which communicative intentions, e.g. surprise, excitation, fatigue.

2) analysis of repetitive movements: repetitive and predictable movements are important. For example, they help to discriminate between pathological movements and movements voluntarily / consciously performed in synchronization with the caregiver or with some musical cues.

4.1.1 Example of Scenario Supported by Sonification

A naturalistic sonic background is present at the beginning of the session: the metaphor is the background sonic landscape coming from an “open window”. This avoids abrupt emergence of interactive sonification, which instead emerges from such sonic landscape and not from silence. Invisible musical sonic events respond to the

child's individual movements and to the movement qualities achieved by the dyad caregiver-child.
Shy and circumscribed movements might cause small sounds (rattles, magic bells, little musical notes, small animals, etc.). Sudden movements may cause louder sounds (drum sounds, fireworks, breaking cymbals). Tapping and hopping movements may cause small series of musical sounds (for example, an ascending musical scale with short and plucked sounds). Large, fluid and continuous movements cause long, imposing sounds (passage of a spaceship or a train, a gust of wind). Light movements and suspensions may cause aerial and ethereal sounds (birds, leaves moved by the wind).

The caregiver accompanies the child in the discovery of these sounds starting from small movements, and slowly introducing him/her to all the nuances that the system can identify. As the session continues, sounds in the background and sounds controlled by movement slowly change, depending on the level of entrainment in the dyad, to keep engagement and avoid annoyance.

The activity is related to the discovery process of the child, where sonification plays an important role to support child awareness of his/her own movement, of the relation with the caregiver, and with the external world.

5. Examples of activities

This section presents a few examples of activities that will be considered in EnTimeMent, as a starting point for the design of the Scenario.

Activities are conceived as carried out in a number of different sessions, according to specific requirements and in compliance with the tolerance and the evaluation of the quality of experience (e.g., pleasure) demonstrated by the child.

In the following we describe a short example to be considered as part of a larger narrative structure, as an interactive storyboard. This example will be iteratively refined following the progress of the interaction design process led in collaboration with the staff of the Gaslini Children Hospital.

5.1Case Study - Giorgio and his mother

Giorgio is a 4 year-old child with cerebral palsy. As a consequence, he is not able to control his movements well, to move smoothly, to feed himself or effectively communicate with others, which threatens learning and participation. His mom Francesca struggles with her child's condition which she hasn't still fully accepted. Therapist know the situation is complex, with the family living far from the hospital, in an area where social assistance and services are less effective.

In cases severe as Giorgio's, in which a complex rehabilitation project is needed, the healing process becomes a life project, with multiple aims and goals unfolding in multiple temporal dimensions. The rehabilitation team has leveraged a "home care unit" that affords the family to live autonomously while having Giorgio monitored by the EnTimeMent technology, and allows to read Giorgio's body communicative signals at multiple temporal scales, in order to:

(At a lower temporal scale), enhance movement control by interpreting bodily sensorimotor and muscular signals to regulate and better tune care and assistance; improve emotion regulation by decoding affective bodily signals and providing most appropriate responses and care.

(At a middle temporal scale), foster attention and motivation by interpreting bodily signals of vigilance, focus and interest; improve control of bodily movements while learning daily-life processes such as feeding and drinking; support emotion regulation by interpreting residual bodily intentional communication.

(At a higher temporal scale), foster planning and control of complex activities such as play and social interaction by decoding participative signals; enhance metacognitive processes by reading resilience signals

5.2 Giorgio recreational/educational family-centered activity/rehabilitation session

A typical whole session of activities is here described. The following specific actions and interactions will be considered as candidate for detailed experiments in EnTimeMent: sit-down and stand-up from a chair (individual action), and the exchange of an object between child and caregiver (dyad interaction). Possible further actions and activities might be considered.

Session description: The child enters the room dedicated to the EnTimeMent Project independently or with his/her own wheelchair/stroller or, in milder cases, walking with orthoses. The child is invited to sit on a wooden chair or a bench and to maintain the most upright and stable possible position, with the feet well placed on the ground. The child is then asked, if able to do so, to stand up and sit down again. The strategies adopted by the child in these steps are monitored (action 1). We than proceed with a welcoming ritual (e.g. song, nursery rhimes with gestures, s). If requested by the child the adult supports him in carrying out simple undressing activities (eg. removing shoes, orthoses, socks ...). The session continues with an interactive game. The therapist/caregiver proposes to the child sitting or standing in front of him the contact/exchange/throw of an object/ball. This type of interaction will be tailored to the child's level of functioning (amount of help required, characteristic of the object to be touched/exchanged, duration of the interaction, goal to be achieved).
The interaction can evolve using a sheet helds with the hands to direct the object towards the partner and obtain an alternating rhythmic exchange (interaction 1). The session can than continues with a construction game (interaction 2) and conclude with a short review of the activities carried out followed by a greeting ritual.

6. Reference Tools and Systems for Classifying, Coding, Evaluatng and Measuring Activities (Capacity and Performance)

Evaluation and coding systems will be chosen taking into account the theoretical framework of the international classification system of functioning (ICF-CY) and the international scientific literature (see D4.10).
In particular, the evaluation and coding systems for objective instrumental detection will be based on the best standardized evaluation tools available in the international scientific literature:
- for interactive behavior: Coding Interactive Behavior Manual - Feldman R - Ramat-Gan; Bar Ilan University;
- for the development profile: for the 0-42 months range - Bayley III development scales,in pre-school age - WPPSI-IV;
- for the sensory characteristics: Sensory Profile 2 (Winnie Dunn) in the different age ranges;

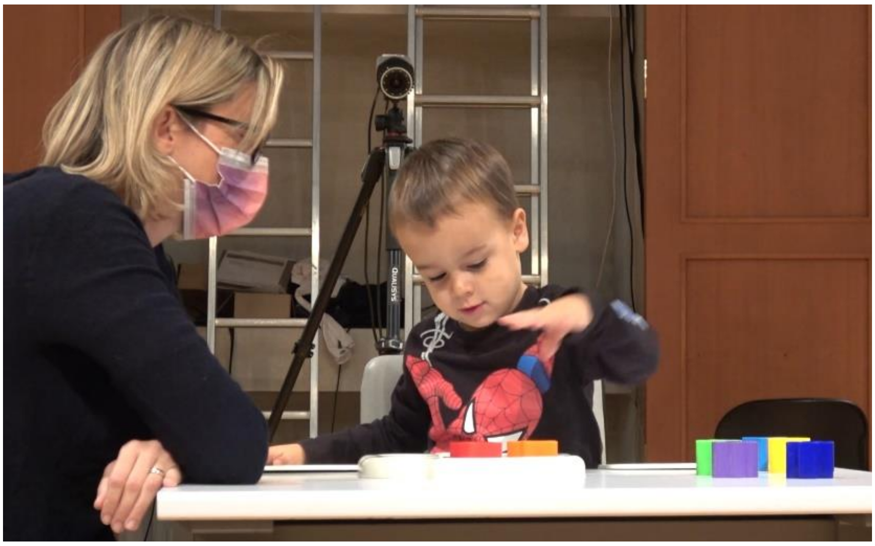
- for praxic skills and motor coordination: some tests of the APCM 2 Protocol (Sabbadini);
- for postural trunk and head control Level of Sitting Scale (LSS) system
- for the upper limbs function: Melbourne Assessment for Unilateral Limb Function or/and Assisting Hand Assessment (AHA);
- for global motor skills: Gross Motor Function Measure (GMFM);
- for adaptive behavior: Vineland Behavior Adaptive Scale.

7. Experimental recordings at the Markerless Motion Capture Campaign

This section shows excerpts from the markerless motion capture recordings done at the 2-week *Markerless Motion Capture Campaign*, November 2021, at Casa Paganini. A number of case studies was selected, in collaboration with the clinical personnel of the Gaslini Hospital, starting from those described in the previous sections, individuated in the Phase 1 of the project.
An analysis and annotation using CIB is in progress.

Use case 1 – caregiver-child: meal

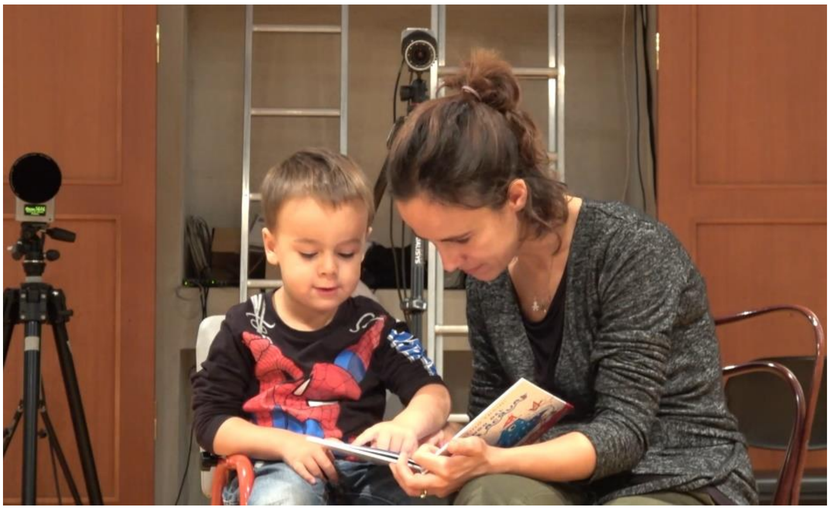
Use case 2 - caregiver – child: assembly game



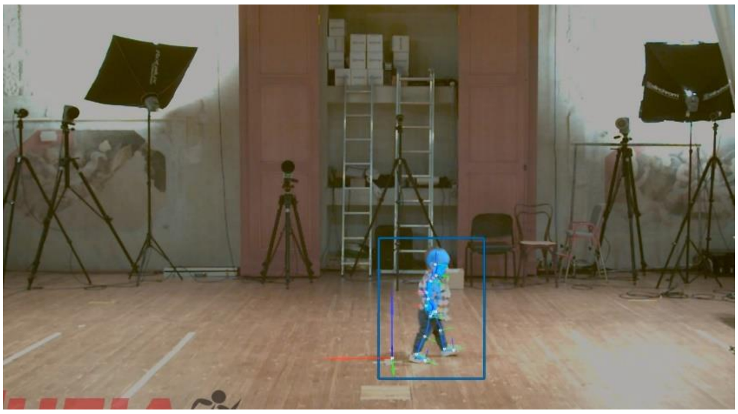
Use case 3 – caregiver-child: fruit cut game

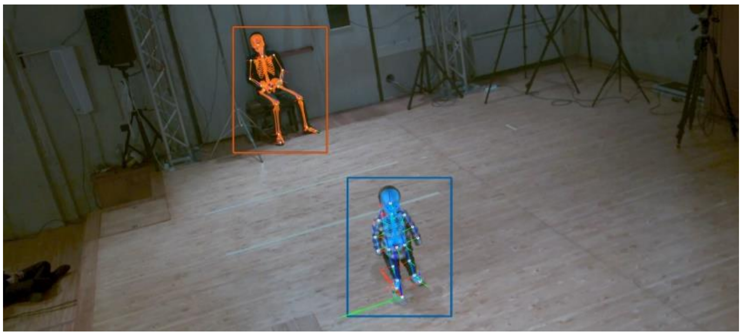
Use case 4 – caregiver-child: tower assembly game

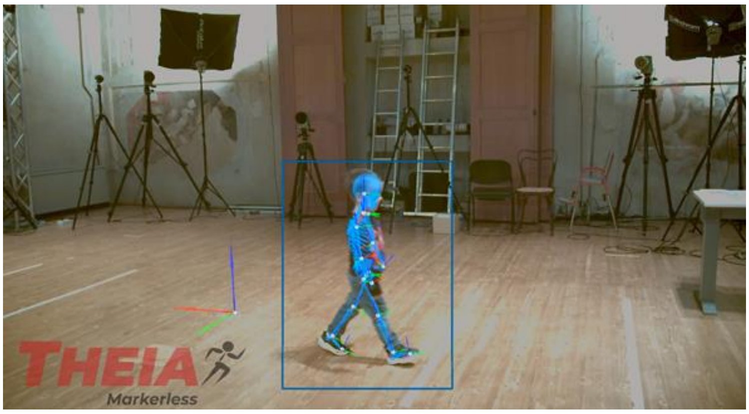
Use Case 5 - Fairy tale



Use case 6: Search and grasp an object in the room (markerless motion capture)







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