Int J of Soc Robotics (2016) 8:471–481
DOI 10.1007/s12369-016-0373-8

CONTINUING EDUCATION

Transitional Wearable Companions: A Novel Concept of Soft Interactive Social Robots to Improve Social Skills in Children with Autism Spectrum Disorder

Beste Özcan[1] · Daniele Caligiore[1] · Valerio Sperati[1] · Tania Moretta[1] · Gianluca Baldassarre[1]

Accepted: 1 July 2016 / Published online: 25 July 2016

Abstract We present a novel concept of interactive devices, called "transitional wearable companions" (TWCs), usable to support therapy and foster social skill development in children with autism spectrum disorder (ASD). TWCs have two distinctive features. First, they are soft interactive devices, which look like tender animals, able to arise attachment emotions and give a continuous reassuring physical contact. Second, TWCs are embedded social robots responding to the child's manipulations by emitting lights, sounds, or vibrations usable for multiple purposes, for example to enhance the child's engagement. TWCs can have additional important features. First, the input–output rules with which they respond to the child's actions can be changed by the therapist/caregiver, for example through a tablet, thus opening a large number of possibilities to foster social interaction. Second, TWCs can have biosensors gathering information on the child's physiological and emotional state, thus offering multiple ways to support the interaction with the child during therapy and daily life. The paper presents the principles underlying TWC design, their possible future enhancements, a first prototype (+*me*) of social TWC, and possible empirical experiment procedures to test the effectiveness of TWC in controlled experiments. For their multifaceted and flexible features, TWCs might become an important tool to enhance ASD children's social abilities in ecological and therapeutic contexts.

Keywords Autism · Social interaction · Therapy · Interactivity · Wearable · Biosensors · Emotional state

1 Introduction

Autism is increasingly considered a pervasive neurodevelopmental disorder [1,2]. It is characterised by a great variation in both quality and gravity of symptoms, overall grouped under the name of *Autism Spectrum Disorder—ASD*. In this work, we focus on the possible treatment of autism involving individuals in the early developmental phases, namely children younger than 10 years old. Autistic children generally exhibit a significant impairment in the social-communicative domain. They rarely initiate social interaction [3–5], often refuse human contact [6], tend to focus on restricted interests and activities, and are inclined to display repetitive behavioural patterns which isolate them from the outer world [7]. Attempts by caregivers to interfere with these stereotyped routines generally provoke a stressful situation for the autistic child. As a main consequence, it can be very difficult to establish a social interaction with the child, with negative repercussions on her/his mental development because social interaction and communication play a key role in children development [8].

A possible psychological interpretation for the pathological behaviours of autistic individuals concerns the expectations and judgements involved in social interactions and

✉ Beste Özcan
bestesi@gmail.com

Daniele Caligiore
daniele.caligiore@istc.cnr.it

Valerio Sperati
valerio.sperati@istc.cnr.it

Tania Moretta
taniamoretta89@gmail.com

Gianluca Baldassarre
gianluca.baldassarre@istc.cnr.it

1 Laboratory of Computational Embodied Neuroscience, Institute of Cognitive Sciences and Technologies, Italian National Research Council (LOCEN-ISTC-CNR), Via S.Martino della Battaglia 44, 00185 Rome, Italy

contexts. The possible unexpected events involved in these situations, usually manageable by healthy people, might appear unsafe or threatening to children with autism who consequently tend to shy away from them [4]. This is consistent with reports where autistic children are described as particularly attracted by highly predictable activities [9,10].

In recent years, this latter observation has been exploited by some therapists who started to use robots, computers, and electronic gadgets during therapeutic sessions because, unlike people, they may be programmed to exhibit highly predictable behaviours [2,11]. For example, computers based products may be set in order to not react to atypical behaviour showed by autistic children such as rocking or screaming as a human would [12]. In this way, the stress and unpredictability caused by social interaction is largely removed during the interaction with a computer [13], a robot, or a mechatronic device. These technological tools may thus represent powerful attractors or mediators, that can be exploited as an easy way in which therapists and researchers can establish a connection with ASD subjects [11]. Children with autism seem to show a preference in establishing a relationship with these artificial agents [14] and often improve their skills after a therapeutic session based on their use. For example, interactive toys may provide predictability by relying on constant cause and effect functions that reassure children and support them in the daily behaviours (e.g., cleaning teeth, travelling in a car [9]). During therapeutic sessions using robots or other artificial agents (e.g., computer simulated avatars) children with autism have a reduction of stereotypical and repetitive behaviours and an improvement of language skills [15,16]. Importantly, predictable robots and objects might mediate social interactions and improve social skills [11,17].

Capitalising on these experiences, we propose here a novel class of interaction devices, called *transitional wearable companions—TWCs*, usable to improve social skills and engagement of children with ASD. The paper is organised as follows. Section 2 illustrates the key features of TWCs. Section 3 reviews existing systems related to TWCs. Section 4 illustrates a first prototype of TWC and how it could be enhanced in the future. Section 5 outlines the experimental protocol of an empirical test directed to test the acceptability and utility of TWCs for children with ASD. Section 6 draws the conclusions of the paper.

2 The Key Features of TWCs

TWC are soft interactive mechatronic devices—social robots—which outwardly look like a tender animal or a security blanket. TWCs have two core defining features, and some additional features, now illustrated in some details (see Fig. 1). The first core feature of TWCs is that they have the powerful reassuring features of what in psychology are called “transitional objects”. Transitional objects are puppets, blankets, or similar objects (e.g., the blanket of Linus, the child character of Shultz’s comics) with a soft touch and a tender look that the child can carry along when she/he independently navigates and explores the environment without the reassuring support of a caregiver (e.g., the mother) [18]. Since expectations and judgements involved in social contexts might appear threatening for children with autism, making social interactions problematic [4], many children with ASD develop an attachment to a transitional object, for example a teddy bear. As transitional objects [19], with their stable presence and features wearable companions can represent a reliable source of soothing and confidence when the autistic child explores novel environments “far” from parents, caregivers and familiar places.

The second core feature of TWCs, also shared with *wearable computers* (also simply called *wearables*), is that they contain an embedded mechatronic device that allows them to react to the actions of the child. In this respect, a wearable companion can be considered a social robot having *actuators* that can emit lights, sounds, and vibrations in response to the child acting on its *touch/interactive sensors*, and these responses are controlled by an on-board computer (e.g., an Arduino board [20]). While typically developing children can be motivated to engage with inanimate object such as transitional objects, children with autism may benefit additional degrees of “animacy and interactivity” to elicit their engagement [21]. The cause–effect regular nature of such type of interaction would give the child a higher sense of control and hence mitigate fearful and avoidance reactions [22]. In this respect, and importantly, since the causal link (contingency) between the actions of the child on the wearable companion’s sensors and the responses of the wearable actuators are governed by an on-board computer, they can be modified via software. This allows a fine regulation of the wearable companion reactions to the child’s actions so as to tailor them on the child’s personal features, level of cognitive development, and emotional structure. Moreover, for their richness and *programmable nature*, the contingencies could be progressively sophisticated (at a pace tuned with the level of development of the child’s cognition and emotions) to foster the child’s exploration of novel features and the development of divergent behaviours leading to “accommodate” to those novel experiences [23].

Alongside the two core defining elements, TWCs can have other additional features empowering their possibilities of employment with children with autism. A first empowering feature is that TWCs can be endowed with wireless communication components (e.g., based on bluetooth or TCP-IP technology) allowing them to exchange information with other mechatronic devices such as external computers, tablets, smartphones, or another TWCs. Importantly, these additional devices might be under the control of another

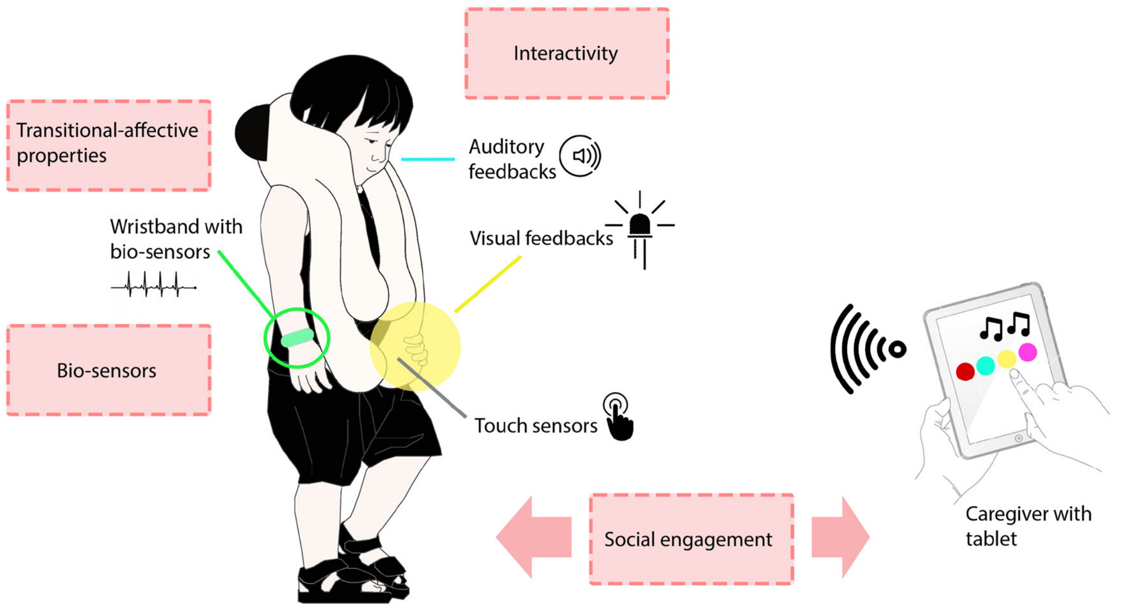

Fig. 1 The schema shows the main features of a *transitional wearable companion* (TWC), in this case a *physiological social transitional wearable companion* (PSTWC). A TWC can be carried along by the child and has engaging affective properties typical of *transitional* objects, for example the wearable resemble a tender animal and is made of soft materials. These features and the physical contact of the wearable give the child a sense of protection and stability thus supporting her/him in the engagement with and exploration of unknown physical and social settings. A TWC contains a mechatronic device with sensors and actuators, i.e. an embedded robot, that can suitably react to the actions of the child. For example, when the child presses a paw of the animal, the wearable responds with the production of various visual and auditory stimuli. A TWC can be a *social TWC* (STWC) if it can connect (e.g., via bluetooth) with external electronic or mechatronic devices, such as a computer, a tablet (as in this case), or another TWC, and these devices are under the control of another human agent, for example the caregiver or another child. These devices allow these other agents to interfere, modulate, modify the ways in which the TWC reacts to the actions of the child, thus giving an important social dimension to the TWC. A TWC can be a *physiological STWC* (PSTWC) if its mechatronic component contains physiological sensors (e.g., to detect the current skin conductance and heart rate of the child). These sensors can be used to allow the TWC to react to the child internal state, for example to manifest to the child herself her affective state through its actuators (e.g., a light pulsing with the child's heart rate), or to give real-time information on the child's emotional state to caregivers, for example to a therapist or a parent via a light intensity or a distant tablet

human agent, such as a therapist, a parent, or a friend child, thus making the TWCs *social transitional wearable companions* (STWCs). The features of STWCs might open important new means to support therapy in unstructured contexts and for the development of social skills in daily life—for example by fostering and enriching the interactions with parents and friends [9]. For example, the caregivers could manipulate the stimuli emitted by the wearable companion (e.g., the type and/or rate of colour, sound, and vibration) to motivate the child's interaction with them [24]. In particular, the child can be progressively led to understand that the pleasurable interactions with the wearable companion depend on the caregivers' intervention (e.g., via the tablet) and this will be a strong motivation for the child to increase the level and quality of social engagement with them.

A second empowering feature of TWCs consists in endowing them with *physiological sensors* alongside with other "external" interactive sensors (e.g., touch sensors), thus leading to have a *physiological social transitional wearable companions* (PSTWCs). By physiological sensors we refer for example to biosensors embedded in a wristband connected to the TWCs or embedded in the wearable companion's main body that can return information on the internal physiological state of the child, for example in relation to internal temperature, heart rate, level of stress (e.g., via skin conductance). Information on the physiological state is very important as the physiological state of the body is strongly related with the emotional state of the child. Indeed, the information on the child physiological state so gathered could be automatically processed based on pattern-recognition and other machine-learning algorithms to infer the emotional state of the child. Thus, the collection and suitable elaboration of information on the child's physiological state could furnish precious real-time knowledge on the current emotional state of the child and how she/he is reacting to current experiences [25–27].

The uses of information returned by the biosensors, used locally by the wearable companion or communicated to external devices, might be employed in several different ways. First, the wearable companion might react to the internal state of the child and not only to her/his overt actions, and thus its contingencies might be modified on the basis of such additional information. For example, the reactions of the TWCs might be tuned down in intensity and variety in correspondence to a higher level of stress of the child. Second, the information on the emotional state of the child might be broadcasted to other agents through the actuators of the wearable companion. For example, colour lights might be used to visually render the current level of stress of the child, so allowing therapists to suitably tune the therapeutic actions, or parents to regulate their behaviour [28]. The rendering of some aspect of the emotional state of the child through sensorial means easily interpretable by the child might also be used to support the development of her/his skills in understanding own emotional states. Third, thanks to the prolonged interaction of the child with the wearable companion, the biosensors might support a prolonged recording of the child's physiological and emotional states in correspondence to different experiences, thus allowing a continuous monitoring of the child development supporting therapeutic decision making.

3 Related Works

The literature offers various options for the treatment of autism, for example reward based training of skills, training of language abilities to build social relationships, improvement of motor skills, use of games as a means to improve social skills [29,30]. Alongside these "traditional" approaches, the development of new technologies is contributing to the emergence of new techniques based on the use of artificial agents (e.g., robots, computer based products, electronic gadget) to improve emotional and social abilities [15,30,31]. The goal of the interactions between the artificial agent and the children might be to stimulate joint attention or to involve in the child-artificial agent relationship a third agent, such as a caregiver, for example to encourage imitative or other resonant behaviours. The artificial agent can also act as a teacher, as a game, or as a means through which the child with autism can express emotions and goals [32]. Combining some benefits of traditional techniques [29] with the use of new technologies may allow the exploration of new (and maybe more effective) alternative routes for the treatment of ASD [30,33]. In this respect, several traditional treatments for social impairments in ASD are based on the training of emotion recognition [34]. The aim of such treatments is to enable ASD individuals to interpret intentions and meanings of people and to anticipate their emotional reactions to typical situations they may encounter in daily lives.

One of the main limitations of these approaches is that they present a limited generalization of the experience to real life situations. The learning process deriving from these treatments indeed uses a limited repertoire of predefined scenarios (e.g. realised by drawings, videos, photographs), and is based on the memorization and interpretation of a scene as a therapeutic setting. Recently, several studies have shown that making the therapeutic setting closer to the real life scenario (e.g. using robots and electronic gadget to evoke elementary emotional states instead of simple photographs) could increase the effectiveness of these treatments [32,35]. However, even in these enriched setups the *children poorly interact* with the artificial agent to cause an emotional states and create social situations. This interaction might be instead very important as it actively engages the children in emotion recognition and resonance processes enhancing social skills [34,36]. The use of robotic agents could greatly enrich the immersiveness of the interaction. For example, the child could caress the robot face (or could smile to the robot) and could observe the effect of the action on the robot (e.g. the robot could emit a sound). The matching between the expected effect and the effective one could reinforce the learning of the emotional understanding.

Another important drawback of traditional treatments for ASD is the lack of the possibility for on-line monitoring of the benefits of the treatments. This is important as it could support the tuning of stimuli and more in general of the therapeutic intervention [24].

TWCs overcomes these limitations by exploiting its transitional and interactive features and also by incorporating some elements of traditional therapeutic approaches (e.g., reward based learning, improvement of motor skills, game). Through TWCs, the emotion detection abilities of the child could be trained by a two-way interaction. First, the child might interact with the body of the TWC that, as a result, might react with signals and actions affecting the child (e.g., emitting lights, sounds, and vibrations). Second, using a PSTWC the caregivers could receive data on the emotional states and activity of the child through the biosensors and other sensors and accordingly she/he could manipulate the stimuli emitted by the companion, for example during a game (e.g., type and/or rate of colour, sound, and vibration) to further motivate the interaction (cf., "LEGO®therapy", [37]). The child could also "feel" what happens as a consequence of the actions of the companion or the caregiver if these are transferred into suitable signals transmitted to the child by the companion. This enrichment of the interaction could train and hence substantially increase the generalization abilities of the children to recognise emotions and other social signals in ecological conditions, and hence it could improve their ability to cope with more complex real life social contexts.

Detecting the emotional state of autistic children is not trivial [24] and most studies done in the past in this field were restricted to measurements in laboratories (e.g., [38,39]). Recently, it has been shown that there is a significant emotion-related information that can be recognized through physiological activity [25]. In this respect, it has been found that in the majority of autism cases there is a dysregulation of the electrophysiological parameters at the basis of autonomic nervous system (ANS) [40–43] with hyperarousal of sympathetic system and dampened parasympathetic vagal tone [44,45]. Smeekens et al. [42] studied the differences in the ANS activity between ASD young males and young males without ASD during social interaction. The results show an increase in heart rate (HR) and in heart rate variability (HRV) in ASD group. Vagal "brake", at the basis of HR modulation, enables rapid engagement and disengagement with objects and people thus promoting social interaction [46]. Abnormalities in HRV, in HR reactivity and in electrodermal activity (EDA) were found in different studies on ASD [26,27,47–49]. In this line, some recent research have started to use these observations to collect data outside the laboratory through the use of biosensors.[1]

Building on these recent approaches, TWCs can deal with the need for on-line monitoring of the effects of therapeutic actions by allowing the collection and integration of information from biosensors, for example used to monitor the emotional state of children (e.g., changes in HR [46]). The use of wearables with biosensors as in PSTWCs contributes to meet the increasing need for ecological monitoring of physiological variables to support medical interventions and therapies outside the clinical setting [50,51]. Information collected with accelerometers embedded in a wristbands might also be used to monitor the effects of treatments [52–54], for example to measure the success of therapies aiming to decrease repetitive movements.

4 TWCs: Architecture and Functioning

4.1 Current Prototype: The *+me* Device

At our laboratory[2] we have developed a first concrete example of TWC [20]. This is still a partial implementation of the general idea, as it includes the features of a STWC but currently it lacks the integration with biosensors. The prototype is called *+me*[3] (see Figs. 2, 3), and outwardly looks like a soft, animal-shaped pillow (see Fig. 4). The four paws form a collar so that the child can wear the *+me* around the neck (see Fig. 5).

An electronic device is embedded within the pillow padding (see Fig. 6). The device is composed by several commercial electronic components, partially hosted on a customised printed circuit board (PCB). The various components, described in Fig. 7, manage the *+me* inputs and outputs. Four capacitive sensors are arranged under the cotton fabric cover of the pillow in correspondence of the paws and detect the childs touch. Four 20 cm long RGB LEDs strip are placed within the paws and can light the animal limbs with different colours. Two speakers are positioned in correspondence to the animal head, so that they are close to childs ears when the pillow is worn. The sound card component can play mp3 files which, in the current experimental setup, reproduce brief sounds or musics. All activities are supported by two Arduino boards. The first board is the main controller of the *+me* and coordinates the software operations (inputs readings, outputs management, onboard computations). The second board is a slave controller employed for the audio management.

The whole device is powered by a 12V LiPo rechargeable battery, ensuring several hours of life and a safe low voltage. The software mastering the cause–effect contingencies (e.g., how the lights and sounds are produced in response to the child's touch of the animal paws), can be modified in real-time through an application running on a tablet (Android operating system). This application, coupled by bluetooth connection to the *+me*, can be controlled by therapists and caregivers [28].

4.2 Future Enhancements of the System

The system we developed, currently under test (see Sect. 5), could be improved in several ways. Here, we briefly illustrate three possible directions of improvement that might be implemented independently or in synergy.

4.2.1 Biosensors Integration

We are developing an improved *+me* prototype that will include all the critic features requested by a PSTWC. This version of the system will be integrated with a wristband with low cost, low power, and non-intrusive biosensors and accelerometers usable for physiological and movement data collection. These will support the detection of HR, HRV, EDA, Skin Temperature (SKT), and movement [6,21,27,52,53]. Such data will be sent to the tablet application to allow the therapist/caregiver, once suitably elaborated, to evaluate in real-time the levels of activity, stress, engagement, and other emotional states of the child. This information will help the therapist/caregiver to have a deeper understanding of the childs emotional state as it might complement the possibly poor information received from the child facial expressions, bodily signals, and verbal communication. This will facilitate a real-time fine tuning of the therapeutic/daily life interactions [7]. Moreover, it will also allow a faster learning by the caregiver of the best way with which to deal with the child, for example to minimise the stress level: indeed, the

[1] Commercial products for physiological data recording are now becoming available at relatively low prices, e.g. see www.empatica.com.

[2] http://www.istc.cnr.it/group/locen.

[3] www.plusme.it.

Fig. 2 Current prototype of *+me*, showing a sequence of possible light combinations. Lights and sounds behaviours depend both on the child, who touches the TWC, and on the therapist/caregiver who manages the input–output functions of the device

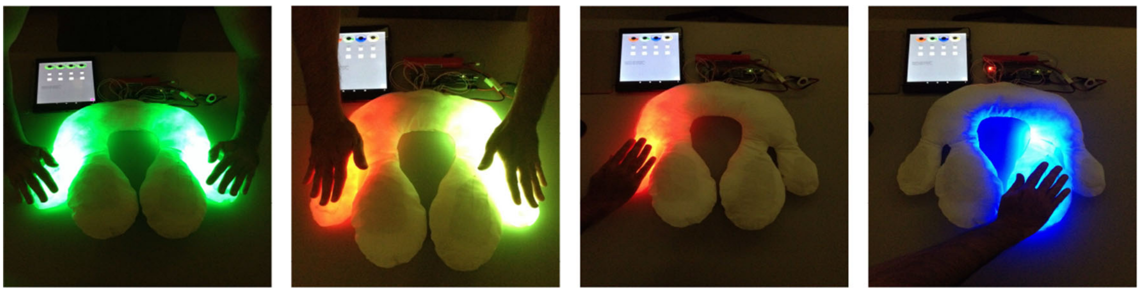

Fig. 3 An early prototype of *+me* showing different light responses based on the location of the hand contact. The touch sensors embedded in the fabric detect even the soft caresses. The colours of emitted lights and sounds can be remotely regulated via a tablet application (in the background)

Fig. 4 A *+me* prototype has been presented to MakerFaire 2015, European Edition. The aspect of the device, characterised by an animal shape and softness, was clearly appealing for children

caregiver will have a real-time feedback on the effects of own behaviour on the child's state. Information on the child's state might also be directly exploited by the wearable companion, for example to adjust the inputs sent to the child and based on sounds, coloured lights, and vibrations (Fig. 1), especially if such information will be suitably processed by an intelligent controller.

4.2.2 Intelligent Controller

Future versions of the *+me* might be provided with more artificial intelligence. This intelligence might implemented in the main Arduino controller embedded in the wearable companion, or reside remotely in the tablet connected with

Fig. 5 The *+me* worn around the neck

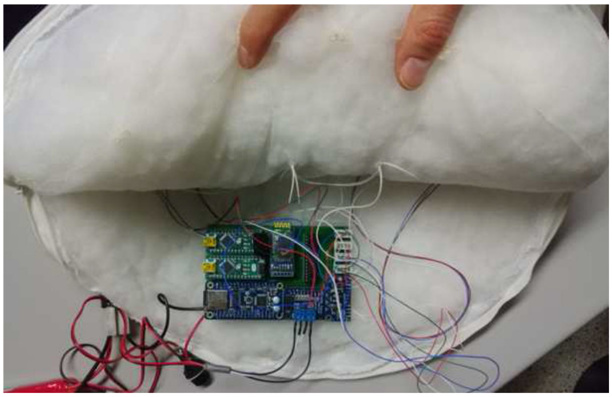

Fig. 6 The PCB embedded in the *+me* padding

the rest of the system via Bluetooth. More intelligence might be used to accomplish two classes of useful functions. First, information from biosensors and other sensors of the system might be suitably processed to produce complex knowledge on the child's emotional state and on the level and quality of his activity. This knowledge might be directly delivered to a therapist/caregiver via the tablet or via the actuators of the wearable companion (e.g., lights), or it might be used to suggest the caregiver possible courses of action [55,56]. For example, the wearable companion might understand that the child is in a stressed condition and so suggest the caregiver to use a less-intrusive, emphatic approach; or it might realise that the child is in a down-state, or bored, and so suggest the caregiver to intervene and engage with her/him. This would thus support a suitable regulation of the caregiver's behaviour so as to improve social interaction and engagement. Also, it could allow the caregiver to learn permanent skills to better interpret the child's language, facial expressions, and body signals. Second, a more intelligent controller might allow the wearable companion itself to autonomously regulate its own behaviour. For example, the companion might monitor the number and frequency of repetitive actions performed by the child on specific parts of its body and understand that the child got trapped in a stereotyped behaviour. On this basis, the companion might decide to interrupt or change the light/sound contingencies to lead the child to engage in other activities that might be proposed him/her by the companion itself.

4.2.3 Smart Moving Textiles

The interaction features of *+me* could be greatly extended if movement capabilities were added to it. Although standard motors (servos) could be embedded into the TWC, this solution is probably not suitable as such actuators are relatively heavy and non compliant. A promising direction lies in the employment of "smart" textiles. These types of solutions appears well fitted to the soft nature of TWCs and would add additional "robotic capabilities" to the device. Smart textiles

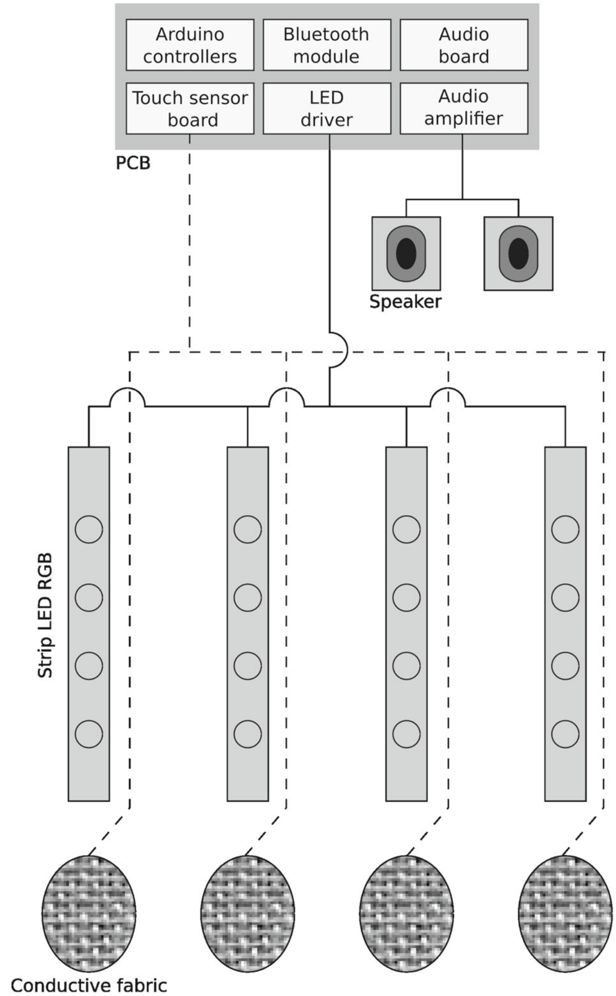

Fig. 7 Schema of the organisation of the *+me* electronic components. A customised printed circuit board (PCB) hosts commercial components: two Arduino Nano controllers (the first performing the main operations of the system, the second performing audio operations); a HC-05 bluetooth module; a board for capacitive touch sensor (MPR121 by Adafruit); a TLC5940 LED driver chip; an audio board (VS105 by Adafruit); a stereo 3.7W audio amplifier (MAX98306 by Adafruit). PCB is connected to: a couple of 4 Ohm 3W stereo speakers for sound output; four 20 cm long 12V RGB LED strips for visual output; four circular patches of transparent conductive copper fabric (by Plug&Wear) for touch input detection

are a new class of fabrics which incorporate wires containing Shape Memory Materials SMM (based on alloys [57] or polymers [58]). These type of materials have the interesting property to react to external stimuli, such as changes in temperature, by modifying their shape and size. This technology is finding interesting applications in areas as clothing [59–62], and garments based on smart moving textiles, capable to shrinking, creasing and rolling-up, and are already available in the market. These interesting properties could be naturally exploited in the wearable companion. For example, a *+me* using a smart fabric under the control of the inner electronic apparatus could nicely hug a child in correspondence to stress peaks so as to increase the child's feeling of protection.

5 Experimental Protocol

A first experimental test with the current prototype has been designed and now being implemented. The test will involve a selected sample of autistic children. The main target of the experiment is to confirm the utility of the features of STWC implemented in the +*me*. In particular we expect that the +*me* will be accepted by children as a lovely comforting companion more than other toys because of its wearable features, interactivity, and social engagement potentialities.

In detail, the experimental protocol will try to investigate the ability of the +*me* (which has interactive, companion-like, and wearable properties) compared to other objects normally used during therapy, in particular: a Chicco®toy (interactive, non "companion-like", non wearable); a pelushe (non interactive, companion-like, wearable); and wooden cubes (non interactive, non companion-like, non wearable). We will measure how the +*me* compares to the other toys with respect to its capacity to capture the attention of children, encourage engagement, and support social interaction. To do this each object will be compared through a number of quantitative indexes measuring the object acceptability during five activities carried out with the children. The sample of participants will be selected within the "Istituto Neurotraumatologico Italiano (INI), Villa Dante Division" and will include patients with a diagnosis of ASD and chronological age between 2 and 6 years. The five activities will be videotaped and organised as follows.

5.1 Observation

In this activity, the child is free to interact with a test object placed on a table 30 cm away from him/her (thus easily reachable by the child). During the activity the experimenter observes the child–object interaction. The activity will involve all the tested object separately. This activity aims at verifying how much each tested object arises the child's interest.

5.2 Wearability

During this activity the experimenter places a test object on the shoulders of the child and observes him. This activity is carried out only with the +*me* and the pelushe to see which of the two objects is better accepted and enjoyable by the child.

5.3 Ability to Adjust Cause–Effect Loop

This is an activity in which the child is free to interact with the test object. The activity is conducted only with the +*me* and the Chicco®toy. During the activity, in the case of the +*me* if the child exhibits a repetitive behavior the experimenter intervenes to break the repetitions thought the tablet. By contrast, in the Chicco®toy case the experimenter intervenes by moving the child's hand to another point of the object. This activity is intended to check if the +*me* compares to the Chicco®toy if used to quench stereotyped behaviours and fixation, problematic symptoms of ASD.

5.4 Activation Request

This is an activity during which the experimenter places the object on a table so that the child can not reach it. The experimenter observes the child and gives the test object to him. After 10 s, the experimenter puts back the test object on the table and observes the child again. This activity is intended to evaluate which object induces a request from the child towards the experimenter in order to get the test object, thus stimulating social engagement.

5.5 Imitative Behavior

This activity is divided in three different phases depending on the features of the objects. During the activity the experimenter executes particular actions on every object in front of child. Then the experimenter gives the object to the child and observes possible child's imitative behaviours. This activity is carried out to verify which of test objects incentives imitative behaviours.

The quantitative behavioural indices that we will record based on camera recordings and direct observation are as follows:

- how long the child touches the object (in seconds);
- how many times the child looks at the object (frequency);
- how many times the child looks the experimenter;
- how many times the child refuses the object or throws it away;
- how many times the child turns away;
- how many times the child smiles;
- how many times the child cries;
- how many times the child engages in a triangulation looks with the object and experimenter;
- how many times the child touches the object and the experimenter;
- how many times the child performs indicative gestures.

6 Conclusions

This paper has proposed the principles of a new concept of social robot, called *transitional wearable companion*—TWC, usable to support social interactions of children with Autism Spectrum Disorder (ASD) and to improve their social skills in both therapeutic and ecological contexts (e.g., home and school). TWCs are soft interactive social robots that give the child a continuous reassuring physical contact and respond to the child's manipulations by emitting lights, sounds, vibrations and other actions. The responses of the TWC are usable to enhance the childs engagement and allow the wearable companion to communicate with him/her and/or with caregivers and therapists of the child. TWCs could also include interfaces, such as tablets or computers, communicating with the main device through Bluetooth (*social TWC*—STWC). This opens up innumerable possibilities for therapists and caregivers to "get in the loop" of the child-wearable companion interactions, for example to remotely monitor the child and intervene on the behaviour of the wearable companion. Finally, STWCs could also include biosensors to collect information on some physiological parameters of the child (*physiological STWC*—PSTWC). This information could be the basis to produce knowledge on the emotional state and activity of the child. This knowledge might be used by caregivers, therapists and also by the wearable companion itself. In the future, PSTWCs' potential to support children and caregivers might be further enhanced in their potentialities by increasing their artificial intelligence and by endowing them with soft actuators allowing the motion of their body. Thanks to these highly flexible features, TWCs could meet the necessity to have customised and personalised health care products for ASD [30,32], and thus become a very useful tool to support both therapy and daily life social interactions of children with such disorder.

Acknowledgments This research has received funds from the European Commission under the 7th Framework Programme (FP7/2007-2013), ICT Challenge 2 "Cognitive Systems and Robotics", project "IM-CLeVeR - Intrinsically Motivated Cumulative Learning Versatile Robots", grant agreement no. ICT-IP-231722. The authours would like to thank M. Aliberti, S. Scaffaro, A. Medda from INI Institute, Villa Dante for the collaboration in developing the TWC general idea, and M. Cicorella from MakeInBo for his help in developing the *+me* hardware.

References

1. van Rijn H, Stappers PJ (2008) The puzzling life of autistic toddlers: design guidelines from the LINKX project. Adv Hum-Comput Interact 2008:1–8
2. Baron-Cohen S, Golan O, Ashwin E (2009) Can emotion recognition be taught to children with autism spectrum conditions? Philos Trans R Soc B: Biol Sci 364(1535):3567–3574
3. el Kaliouby R, Robinson P (2003) Therapeutic versus prosthetic assistive technologies: the case of autism. Computer Laboratory, University of Cambridge. Technical Report
4. Konstantinidis EI, Luneski A, Frantzidis CA, Costas P, Bamidis PD (2009) A proposed framework of an interactive semi-virtual environment for enhanced education of children with autism spectrum disorders. In: 22nd IEEE international symposium on computer based mediac systems. IEEE, August 2009, Albuquerque, pp 1–6
5. Funahashi A, Gruebler A, Aoki T, Kadone H, Suzuki K (2014) Brief report: the smiles of a child with autism spectrum disorder during an animal-assisted activity may facilitate social positive behaviors-quantitative analysis with smile-detecting interface. J Autism Dev Disord 44(3):685–693
6. Jimenez A (2013) Physiological sensor. Ph.D. dissertation, Departement of Electrical and Computer Engineering, University of Louisville
7. Welch K (2012) Physiological signals of autistic children can be useful. IEEE Instrum Meas Mag 15(1):28–32
8. Takano Y, Suzuki K (2014) Affective communication aid using wearable devices based on biosignals. In: Proceedings of the 2014 conference on interaction design and children - IDC '14, pp. 213–216
9. Dsouza A, Barretto M, Raman V (2010) Uncommon sense: interactive sensory toys that encourage social interaction among children with autism. Workshop paper presented at IDC, vol 12
10. Baron-Cohen S (1995) Mindblindness: an essay on autism and theory of mind Ba, Ed. MIT press, Cambridge
11. Pennisi P, Tonacci A, Tartarisco G, Billeci L, Ruta L, Gangemi S, Pioggia G (2016) Autism and social robotics: a systematic review. Autism Res 9(2):165–183
12. Powell S (1996) The use of computers in teaching people with autism. In: Autism on the agenda: papers from a national autistic society conference. London
13. Farr W, Yuill N, Raffle H (2010) Social benefits of a tangible user interface for children with autistic spectrum conditions. Autism: Int J Res Pract 14(3):237–252
14. Luyster R, Gotham K, Guthrie W, Coffing M, Petrak R, Pierce K, Bishop S, Esler A, Hus V, Oti R et al (2009) The autism diagnostic observation scheduletoddler module: a new module of a standardized diagnostic measure for autism spectrum disorders. J Autism Dev Disord 39(9):1305–1320
15. Pioggia G, Igliozzi R, Ferro M, Ahluwalia A, Muratori F, De Rossi D (2005) An android for enhancing social skills and emotion recognition in people with autism. IEEE Trans Neural Syst Rehabil Eng 13(4):507–515
16. Robins B, Dautenhahn K, Boekhorst RT, Billard a (2005) Robotic assistants in therapy and education of children with autism: can a small humanoid robot help encourage social interaction skills? Univers Access Inf Soc 4(2):105–120
17. Trimingham M (2010) Objects in transition: the puppet and the autistic child. J Appl Arts Health 1(3):251–265
18. Winnicott DW (1953) Transitional objects and transitional phenomena a study of the first not-me possession. Int J Psychoanal 34:89–97
19. Stevenson O (1954) The first treasured possession: a study of the part played by specially loved objects and toys in the lives of certain children. Psychoanal Study Child 9:199–217
20. Özcan B (2014) Motivating children with autism to communicate and interact socially through the + me wearable Device. In: Paglieri F, Ferretti F (eds) Nea-Science: Giornale Italiano di Neuroscienze, Psicologia e Riabilitazione. Salerno, Italy, pp 65–71
21. Elias JZ, Morrow PB, Streater J, Gallagher S, Fiore SM (2011) Towards triadic interactions in autism and beyond: transitional objects, joint attention, and social robotics. Proc Hum Factors Ergonom Soc 55(1):1486–1490
22. Brok JCJ, Barakova EI (2010) Engaging autistic children in imitation and turn-taking games with multiagent system of interactive lighting blocks. In: Entertainment computing ICEC 2010, series (Lecture notes in computer science), vol 6243. Springer 2010, pp 115–126
23. Caligiore D, Tommasino P, Sperati V, Baldassarre G (2014) Modular and hierarchical brain organization to understand assimilation, accommodation and their relation to autism in reaching tasks: a developmental robotics hypothesis. Adapt Behav 22(5):304–329
24. Kientz JA, Hayes GR, Westeyn TL, Starner T, Abowd GD (2007) Pervasive computing and autism: assisting caregivers of children with special needs. IEEE Pervasive Comput 1:28–35

25. Picard RW (2009) Future affective technology for autism and emotion communication. Philos Trans R Soc B: Biol Sci 364(1535):3575–3584
26. Chang MC, Parham LD, Blanche EI, Schell A, Chou C-P, Dawson M, Clark F (2012) Autonomic and behavioral responses of children with autism to auditory stimuli. Am J Occup Ther 66(5):567–576
27. Kushki A, Drumm E, Mobarak MP, Tanel N, Dupuis A, Chau T, Anagnostou E (2013) Investigating the autonomic nervous system response to anxiety in children with autism spectrum disorders. PLoS One 8(4):e59730
28. Fletcher RR, Poh MZ, Eydgahi H (2010) Wearable sensors: opportunities and challenges for low-cost health care. In: Proceedings of 32nd international conference of the IEEE engineering in medicine and biology society (EMBC'10), Buenos Aires, Argentina, September 2010, pp 1763–1766
29. Campbell M, Schopler E, Cueva JE, Hallin A (1996) Treatment of autistic disorder. J Am Acad Child Adolesc Psychiatry 35(2):134–143
30. Lofthouse N, Hendren R, Hurt E, Arnold LE, Butter E (2012) A review of complementary and alternative treatments for autism spectrum disorders. Autism Res Treat, vol 2012, article ID 870391
31. Harris A, Rick J, Bonnett V, Yuill N, Fleck R, Marshall P, Rogers Y (2009) Around the table: are multiple-touch surfaces better than single-touch for children's collaborative interactions? In: Proceedings of the 9th international conference on computer supported collaborative learning (CSCL09), vol 1, pp 335–344
32. Scassellati B, Admoni H, Matarić M (2012) Robots for use in autism research. Annu Rev Biomed Eng 14(1):275–294
33. McPartland JC, Coffman M, Pelphrey KA (2011) Recent advances in understanding the neural bases of autism spectrum disorder. Curr Opin Pediatr 23(6):628–632
34. Winkielman P (2010) Embodied and disembodied processing of emotional expressions: insights from autism spectrum disorders. Behav Brain Sci 33(6):463–464
35. Kozima H, Nakagawa C, Yasuda Y (2005) Interactive robots for communication-care: a case-study in autism therapy. In: International workshop on robot and human interactive communication, (ROMAN 2005). IEEE, pp 341–346
36. Andreae H, Andreae P, Low J, Brown D (2014) A study of auti: a socially assistive robotic toy. In: Proceedings of the 2014 conference on interaction design and children (IDC '14), 2014, pp 245–248
37. Owens G, Granader Y, Humphrey A, Baron-Cohen S (2008) Lego therapy and the social use of language programme: an evaluation of two social skills interventions for children with high functioning autism and asperger syndrome. J Autism Dev Disord 38(10):1944–1957
38. Schachter S, Singer J (1962) Cognitive, social, and physiological determinants of emotional state. Psychol Rev 69(5):379–399
39. Liu C, Conn K, Sarkar N, Stone W (2008) Physiology-based affect recognition for computer-assisted intervention of children with autism spectrum disorder. Int J Hum-Comput Stud 66(9):662–677
40. Ming X, Bain JM, Smith D, Brimacombe M, Von-Simson GG, Axelrod FB (2011) Assessing autonomic dysfunction symptoms in children: a pilot study. J Child Neurol 26(4):420–427
41. Schaaf RC, Benevides TW, Leiby BE, Sendecki JA (2013) Autonomic dysregulation during sensory stimulation in children with autism spectrum disorder. J Autism Dev Disord 45(2):461–472
42. Smeekens I, Didden R, Verhoeven EWM (2013) Exploring the relationship of autonomic and endocrine activity with social functioning in adults with autism spectrum disorders. J Autism Dev Disord 45(2):495–505
43. Wang Y, Hensley MK, Tasman A, Sears L, Casanova MF, Sokhadze EM (2016) Heart rate variability and skin conductance during repetitive TMS course in children with autism. Appl Psychophysiol Biofeedback 41(1):47–60
44. Klusek J, Roberts JE, Losh M (2015) Cardiac autonomic regulation in autism and Fragile X syndrome: a review. Psychol Bull 141(1):141–175
45. Patriquin MA, Lorenzi J, Scarpa A (2013) Relationship between respiratory sinus arrhythmia, heart period, and caregiver-reported language and cognitive delays in children with autism spectrum disorders. Appl Psychophysiol Biofeedback 38(3):203–207
46. Porges SW (2001) The polyvagal theory: phylogenetic substrates of a social nervous system. Int J Psychophysiol 42(2):123–146
47. Hutt C, Forrest SJ, Richer J (1975) Cardiac arrhythmia and behaviour in autistic children. Acta Psychiatr Scand 51(5):361–372
48. Hirstein W, Iversen P, Ramachandran VS (2001) Autonomic responses of autistic children to people and objects. Proc R Soc Lond Ser B: Biol Sci 268:1883–1888
49. Palkovitz RJ, Wiesenfeld AR (1980) Differential autonomic responses of autistic and normal children. J Autism Dev Disord 10(3):347–360
50. Tegler B, Sharp M, Johnson MA (2001) Ecological monitoring and assessment network's proposed core monitoring variables: an early warning of environmental change. Environ Monit Assess 67(1–2):29–56
51. Poh M-Z, Swenson NC, Picard RW (2010) A wearable sensor for unobtrusive, long-term assessment of electrodermal activity. IEEE Trans Biomed Eng 57(5):1243–1252
52. Albinali F, Goodwin MS, Intille SS (2009) Recognizing stereotypical motor movements in the laboratory and classroom: a case study with children on the autism spectrum. In: Proceedings of the 11th international conference on Ubiquitous computing, pp 71–80
53. Pan C-Y, Tsai C-L, Hsieh K-W, Chu C-H, Li Y-L, Huang S-T (2011) Accelerometer-determined physical activity among elementary school-aged children with autism spectrum disorders in taiwan. Res Autism Spectr Disord 5(3):1042–1052
54. Haswell CC, Izawa J, Dowell LR, Mostofsky SH, Shadmehr R (2009) Representation of internal models of action in the autistic brain. Nat Neurosci 12(8):970–972
55. Rani P, Sarkar N (2004) Emotion-sensitive robots: a new paradigm for human-robot interaction. In: 4th IEEE/RAS/international conference on humanoid robots. IEEE, 2004. Los Angeles, pp 149–167
56. Hyun KH, Kim EH, Kwak YK (2010) Emotional feature extraction method based on the concentration of phoneme influence for humanrobot interaction. Adv Robot 24:47–67
57. Jani JM, Leary M, Subic A, Gibson MA (2014) A review of shape memory alloy research, applications and opportunities. Mater Des 56:1078–1113
58. Ratna D, Karger-Kocsis J (2008) Recent advances in shape memory polymers and composites: a review. J Mater Sci 43(1):254–269
59. Hu J (2007) Shape memory polymers and textiles. Elsevier, New York
60. Hu J, Chen S (2010) A review of actively moving polymers in textile applications. J Mater Chem 20(17):3346–3355
61. Vili YYC (2007) Investigating smart textiles based on shape memory materials. Text Res J 77(5):290–300
62. Van Langenhove L, Hertleer C, Schwarz A (2012) Smart textiles: an overview. In: Intelligent textiles and clothing for ballistic and NBC protection, vol 2012. Springer, New York, pp 119–136

Beste Özcan in 2009 she got a M.A. at Department of Interior Architecture and Environmental Design, Faculty of Fine Arts, Hacettepe University, Ankara (Turkey). In 2014 she got an International Ph.D. in Design and Innovation at Second University of Naples (Italy). She is interested in cognitive sciences, interactive and wearable computing, social innovation, AI, robots, the future, sci-fi, art, and everything in between. She is currently an intern at Institute of Cognitive Sciences and Technologies, National Research Council, ISTC-CNR, (Rome, Italy). (www.beste-ozcan.com)

Daniele Caligiore received a Master Degree in Electronics Engineering at the University of Catania (Italy) in 2003, and a Ph.D. in Biomedical Engineering at the University Campus Bio-Medico di Roma (Italy) in 2011. During his Ph.D. he was visiting scholar at the Centre for Robotics and Neural Systems and at the School of Psychology (University of Plymouth, UK) and at Embodied Cognition Lab (Universita' of Bologna, Italy). Since 2004 he works as a researcher with the Institute of Cognitive Sciences and Technologies, National Research Council (Rome, Italy). He has participated to several European projects in the field of embodied cognition and developmental robotics: MindRACES—from Reactive to Anticipatory Cognitive Embodied Systems; ROSSI—Emergence of communication in RObots through Sensorimotor and Social Interaction; IM-CLeVeR—Intrinsically Motivated Cumulative Learning Versatile Robots. His research interests include developmental robotics, embodied cognition, system-level computational neuroscience, brain cortical and sub-cortical hierarchies; reinforcement learning. He has authored/co-authored about 70 peer-reviewed publications appeared in international journals, books and conference proceedings. Recently, he was guest-editor for a consensus paper of the journal 'Cerebellum' titled 'Towards a systems-level view of cerebellar function: the interplay between cerebellum, basal ganglia and cortex'. (www.istc.cnr.it/people/daniele-caligiore).

Valerio Sperati in 2006 he got an M.A. in Psychology at the University of Rome 'La Sapienza'. From 2007 to now he is a Temporary Researcher at the Institute of Cognitive Science and Technologies, National Research Council, ISTC-CNR (Rome, Italy), participating to the following European projects: "ECAgents: Embodied and Communicating Agents"; "Swarmanoid: Towards Humanoid Robotic Swarms"; "IM-CLeVeR: Intrinsically Motivated Cumulative Learning versatile Robots.". He is currently a Ph.D. student in Computer Science at University of Plymouth (UK). (www.istc.cnr.it/people/valerio-sperati)

Tania Moretta in 2011 she got a B.A. in 'Sciences and Psychological Technics for Clinic Analysis and Evaluation of Cognitive Processes', and in 2014 a M.A. in 'Cognitive Neuroscience and Psychological Rehabilitation', both at University of Rome 'La Sapienza'. She is currently intern at Institute of Cognitive Science and Technologies, National Research Council, ISTC-CNR (Rome, Italy).

Gianluca Baldassarre in 1998 he got a B.A. and M.A. in Economics at the University of Rome 'La Sapienza'. In 1999 he got an M.Sc. in Cognitive Psychology and Neural Networks at the same university. In 2003 he got a Ph.D. in Computer Science at the University of Essex, UK (research on 'Planning with Neural Networks'). Then he did a postdoc at the Institute of Cognitive Sciences and Technologies, National Research Council, ISTC-CNR (Rome, Italy), working on swarm robotics. From 2006 he is a Researcher at ISTC-CNR and coordinates the Research Group called 'LOCEN—Laboratory of Computational Embodied Neuroscience'. In 2006–2009 he was Team Leader of the EU project 'ICEA—Integrating Cognition Emotion and Autonomy'; in 2009–2013 he was the Coordinator of the European Integrated Project 'IM-CLeVeR—Intrinsically-Motivated Cumulative-Learning Versatile Robots'; in 2016–2020 is being the Coordinator of the EU FET project 'GOAL-Robots—Goal-based Open-ended Autonomous Learning Robots'. His research interests are on the architecture and learning mechanisms supporting the cumulative acquisition of multiple sensorimotor skills, driven by extrinsic and intrinsic motivations, in animals, humans, and robots. He is also interested in higher-level embodied cognition grounded on and serving those processes. He studies these topics following two synergistic approaches: (a) through biologically-constrained computational models, with the aim of understanding brain and behaviour; (b) through machine-learning and robotic approaches, with the aim of producing new useful artificial intelligence algorithms and robots. He has over 100 international peer-review publications. (www.istc.cnr.it/people/gianluca-baldassarre).