**State of the art of literature:**

**Prospecting and literature review   
around research on motor collaboration   
in Autism Spectrum Disorder**

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This literature review was carried out as part of the project

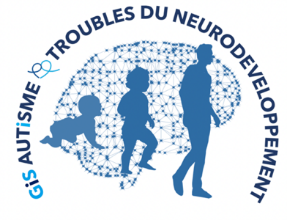
"Software for joint training of collaborative social interaction and motor skills in Autism Spectrum Disorder".

This project is a winner of the Call for Autism and New Technologies projects, coordinated by FIRAH and supported by the Orange Foundation and the UEFA Children's Foundation.

Work done by:

TEDyBEAR and LIMSI-CNRS

The project was supported by: ****





Web sites :

<https://mimetic.limsi.fr/>

<https://www.firah.org/fr/logiciel-pour-l-entrainement-combine-a-l-interaction-sociale-cooperative-et-a-l-apprentissage-moteur.html>



The mission of the International Foundation for Applied Research on Disability (FIRAH, [**http://www.firah.org/)**](http://www.firah.org/) revolves around 2 complementary and interrelated axes:

1/ The selection and funding of applied research projects on disability through its annual calls for projects,

2/ The coordination of the Applied Research and Disability Resource Center. The Resource Center is a collaborative space for knowledge sharing concerning applied research on disability. It wishes to put research on disability at the service of field actors[[1]](#footnote-1) by considering their needs and expectations by facilitating the setting up of applied research projects, disseminating and promoting their results.



[**http://www.firah.org/centre-ressources/**](http://www.firah.org/centre-ressources/)

Tedybear 

Tedybear is a group of experimental medical-social centers dedicated to the education of young children with Autism Spectrum Disorder (ASD) between the ages of 3 and 11, most of whom are non-verbal. These centers are approved by the ARS d'Ile de France. One is located in Saint-Cloud, the other more recent one is in Paris.

TEDyBEAR has developed an innovative pedagogical concept based on inclusive education and coordination with family and caregivers.

With the goal of inclusive education:

* Sharing of time between the school and the center
* Coordination with the school: participation in the ESS, GEVASCO, setting up liaison notebooks, visits to the center by teachers and AVS, and by liberal therapists (speech therapist, psychomotricist, occupational therapist).

In order to coordinate with the family

* Teaching notebook handed out every weekend with the referent psychologist's weekly sheet, monthly curves of positive and negative behaviors,
* Weekly educators' sheet providing information on self-sufficiency and social adaptation to peers; daily relay tablet to families showing clips from the day.
* In return, a weekly form filled out by the parents and providing information on behaviour at home during the week.

Tedybear works in 1/2/3: one child for a psychologist during the therapies, 2 children for a psychologist for the pedagogical activities, 3 children for an educator for the activities relaying with the school in the field of socialization.

The pedagogical work is of the neuro-educational type with the social brain exercise as a base. A particular focus is placed on imitation, which is central to development in that it is closely related to major functions, perception, action, language, and is the initial support for communication and learning.

Therapies are of two types: imitation to develop non-verbal communication and observational learning, and Kinect to develop body awareness and calibration of spatial organization.

LIMSI-CNRS 

The Laboratoire d'Informatique pour la Mécanique et les Sciences de l'Ingénieur (LIMSI) is a multidisciplinary research laboratory that brings together researchers and teacher-researchers from different disciplines of Engineering and Information Sciences as well as Life Sciences and Human and Social Sciences.

Administratively, the LIMSI (UPR3251) is a unit of the CNRS, mainly attached to the Institute of Information Sciences and Interactions of the CNRS (INS2I). The LIMSI is also associated by agreement with the University of Paris-Sud, with which the Unit has long-standing and close links. LIMSI develops numerous collaborations with university laboratories as well as with research units associated with engineering schools within the Information and Communication Sciences and Technologies (ICST) departments of IDEX Paris-Saclay. The Human-Machine Communication department conducts research consisting in analyzing, understanding and modeling the interactions between humans and artificial systems in the most varied contexts and according to the most varied modalities such as haptic, tangible, gestural and ambient interactions. The CPU group involved in this project focuses on the psychology of non-verbal and collective affective interactions in humans and on the design of human-machine interfaces involving them.

This literature review is presented to you by the Applied Research and Disability Resource Center coordinated by FIRAH. It was implemented in the framework of the research "Software for training combined with collaborative social interaction and motor learning in autism spectrum disorder". The literature review was written by Jacqueline Nadel, Tom Giraud, Jean-Claude Martin, Elise Prigent.

The objective of this literature review is to take stock of the state of knowledge in applied research on the concept of motor collaboration.

What FIRAH understands by applied disability research terms:

* It is first and foremost a research project in the strictest sense of the word, obeying its rules of method and rigor, allowing the implementation of a scientific approach, and involving teams of one or more researchers or teacher-researchers whose research is one of their statutory missions.
* Applied research is different from basic research. Its objective is to increase the social participation and autonomy of people with disabilities. It does not only aim at producing theoretical knowledge, but also at solving practical problems related to the needs and concerns of people with disabilities and their families. Collaboration between these people, professionals and researchers is therefore fundamental to the conduct of this type of research.
* In this sense, this type of research is intended to produce directly applicable results. In addition to classic publications (articles, research reports), applied research is intended to produce other publications, called "application supports", which can take different forms: development of good practices, methodological guides, training supports, etc., and are intended for different actors (disabled people, professionals, institutions).

This work does not aim to be exhaustive but to identify results and knowledge produced by research work that can be useful to actors in the field to improve the quality of life and social participation of people with disabilities.

NB: For accessibility reasons, the text is not justified.

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# Edito

**Motor Collaboration in Autism Spectrum Disorder:**

**LITERATURE REVIEW**

This document is the literature review of the research "Software for Training Combined with Collaborative Social Interaction and Motor Learning in Autism Spectrum Disorder". A literature review is an essential prerequisite for any research work. Indeed, the aim is to collect, organize and valorize the research carried out in this field. This literature review therefore provides an overview of the knowledge derived from the existing literature on collaborative motor skills in autism spectrum disorders and the innovative methods likely to help train these skills. Its objective is to provide actors in the field with knowledge that will enable them to better understand the issues related to the importance of motor skills as a basis for socialization.

**The research project "**Software for Training Combined with Collaborative Social Interaction and Motor Learning in Autism Spectrum Disorder**".**

The research project brings together researchers in computer science, cognitive psychology and developmental psychopathology with field professionals in autism, psychologists and educators.

J-C Martin and his team of researchers in Human-Computer Interaction at LIMSI-CNRS are piloting the project in close interaction with J. Nadel and his team of autism professionals, parents and diagnosed children. The associations concerned, professionals and parents participate in the development of the tool.

The research examines the skills involved in achieving motor collaboration between two people: what skills are needed to carry an object that is too heavy or bulky for two people to carry alone? or to lift while the other person pushes? how do these skills play a role in the interest that children with autism may have in helping others? how can they be helped, through new technologies, to acquire these skills? These are the questions that our literature review will address. The promotion of equal opportunities is aimed at the development of collaborative motor skills that can facilitate access to professional tasks, sports activities and social interactions with concrete consequences. The software will be applicable to different forms of autism: with or without communicative language, with or without motor deficit, and at different ages: children, adolescents and adults. The application supports provided by the project will be put at the service of the actors in the field who will be able to use them free of charge to participate in the development of motor and social skills of people with autism.

# Introduction

Given the symptomatology of this neurodevelopmental disorder characterized by severe deficits in social interaction and communication (APA, 2013), research has initially focused on social development. Joint attention deficit has been demonstrated (Baird et al., 2000; Mundy, Sigman & Kasari, 1990) and its role in early detection (Baron-Cohen et al., 1992). This social skill comes into play in collaborative tasks as it relates to visual convergence on a target, but studies rarely make it a component of motor action. Recent research on early signs has shown that motor specificities are among the earliest clues to autism risk (Bryson et al., 2007; Ozonoff et al., 2008; Zwaigenbaum et al., 2005). This has motivated targeted studies on basic postural and motor skills such as resisting gravity (Bullinger, 2015), or being capable of postural anticipation (Schmitz, Martin & Assaiante, 2002). Motor sequences have been the subject of studies showing that they are achieved at the level of their organization in the service of a finalized action (Rinehart, Bradshaw, Brereton & Tone, 2001). These elements are very useful to take into account when developing collaborative tasks, but they concern individual motor skills applied to the physical environment, not to a social partner. Yet motor skills are considered the basis for the development of socialization (McDonald, Lord & Ulrich., 2013).

Many situations involving interaction with physical objects require collaboration with someone else: an object that is too heavy to carry alone, an object that is too large to hold with both hands, an object that is too slippery to hold with both arms, a material that is complicated to handle alone... Since these situations involve the other person, one wonders what children with Autism Spectrum Disorder (ASD) are capable of in this area, as they have such difficulties in social interaction. It can also be hypothesized that developing this concrete form of collaboration can improve social relationships as well as motor skills. This question is all the more interesting since helping the other person physically does not require talking to each other, and therefore a situation of motor collaboration can include non-verbal people. What does the literature tell us about this?

We will attempt to answer this question by analyzing the articles that study the abilities and difficulties of people with autism in situations of motor tasks in pairs. We will see that different terms are used by the authors to describe the relationships developed. We will describe the tasks used. This will be the first part of our literature review article. Once we have explored these elements and synthesized the results concerning populations with ASD, we will leave the floor to our computer scientists who will explore in a second part the literature on the use of new technologies in devices for training people with ASD in motor tasks in pairs.

Finally, in a third part, we will look at existing motor drive systems that use new technologies.

# Literature review

## Autism and motor action in pairs: concepts, abilities involved, devices and results

***Concepts or keywords***

There are several terms that can be used to describe two-way motor action situations. These terms are: motor coordination, joint activity, motor interaction, motor cooperation and motor collaboration. When it comes to describing the situation or type of task, the term most commonly used in English is joint action. When it comes to describing the capacities involved, the term motor coordination is the most general, with the other terms best used to specify the type of coordination involved. Sometimes, however, different terms may be used in the same article, indicating that they are considered synonymous. As we shall see in our review, there is reason to ask the following question: Is there a difference in the motor and social skills to be developed depending on whether we are talking about collaboration or motor cooperation for example? The devices created by researchers can help us understand why they talk about cooperation rather than collaboration or motor interaction rather than joint action.

Motor coordination being the most general keyword including all the others, we will analyze the capacities involved in this framework, specifying them to the type of pair action if necessary.

***Abilities involved in motor coordination***

First of all, it should be noted that this term concerns both a solitary activity and an activity for two. You can lace your shoes with two people or lace them by yourself. Both cases involve motor coordination, but at a different level. When lacing alone, both hands coordinate internally, while when lacing in pairs, we must coordinate our hand with the other hand. This is not without problems: the partner may have faster or slower movements than ours, he may want to cross the lace while we want a straight lacing, he may start doing a single loop while we are trying to do a double loop. Decidedly, to lace your shoes together, you have to agree with your partner, synchronize your rhythms, have a plan of action. These skills are dyadic variables, i.e. they are expressed within the framework of a dynamic system made up of two people. We are in a social situation.

* 1. Intra-individual motor coordination

In order to achieve motor coordination in pairs, one must already be able to achieve individual motor coordination. A meta-analysis of 51 studies provides us with an overview (Fournier, Hass, Naik, Lodha and Cauraugh, 2010). It considers motor reaction time, precision of movement, rate of adaptation, locomotion velocity, pressure force, balance stability and standard motor scales, asking the question whether motor coordination deficits are a major characteristic underlying the autism spectrum disorder: the authors' answer is yes, particularly in its postmotor aspects (see fact sheet). As an extension of the meta-analysis, a study measures on a platform the postural stability of children with ASD from 3 to 16 years old. The authors show that an immature postural system is a factor limiting the emergence of other motor skills, especially when it comes to goal-oriented activities. According to the authors, postural balance is all the more necessary for activities that involve dynamic modulation of the joints (Radonovich, Fournier & Hass, 2013), including the possibility of performing performances involving the linking of several sequences. It should be added that motor sequences have been the subject of studies showing that the deficit is also located at the level of their cognitive organization in the service of a finalized action (Rinehart, Bradshaw, Brereton & Tone, 2001): to physical skills are added cognitive skills for action planning.

The idea of a global motor deficit in autism is not shared by all specialists. For example, in a study of object grasping and grip strength, no differences were found between children with ASDs between the ages of 2 and 6 and typical or developmentally delayed children. The timing of the action, on the other hand, differentiates children with ASD from typical children, but not from children with developmental delays. The conclusion of the study suggests a delay in motor coordination rather than a specific disorder (David, Baranek, Wiesen, Miao & Thorpe, 2012). It should be noted, however, that in this study the child had to lift an object while sitting. Therefore, neither gross motor skills nor postural balance are at stake. The sitting position allows for manual motor skills that can be challenged by standing in the case of difficult postural balance.

Curiously, an essential element of a motor skill directed towards a goal escapes research: knowledge of one's body. If the child does not make the link between what he feels he is doing and what he sees, what motor coordination for two can be expected? We detect this type of deficit using the kinect platform (Nadel & Poli, 2018). Kinect is a motion sensor camera. The child sees himself on screen without image inversion. Some non-verbal children with severe autism are not at all interested in this two-dimensional double which makes the same movements as them in synchrony. A whole therapy will follow to bring out the coupling of proprioception and vision. This basic condition of motor coordination in pairs should not be forgotten.

* 2. Interindividual motor coordination

Information about individual motor skills in autism is very useful to consider in tasks involving motor coordination between two people. Thus, the fragility of postural balance can affect the postural anticipation necessary for motor collaboration with a partner (Schmitz, Martin, & Assaiante, 2002). However, the addition of two individual motor skills is not sufficient to achieve successful motor action between two people. As with any interaction between two people, the behavior of the other person must be considered. This is a very important point that justifies considering motor skills as the basis for the development of socialization (McDonald, Lord & Ulrich, 2013). Several social skills are involved in pair motor skills.

2.1. The social components of inter-individual motor coordination

*2.1.a. Ability to follow the other's gaze*

The ability to follow the direction of the other's gaze enables joint attention, which plays an important role in joint action (Sebanz, Bekkering, & Knoblich, 2006). This social skill comes into play in pair motor tasks as it relates to visual convergence on a target. In an imitation situation where a robot is the initiator of the imitation, the robot looks or not at the future location of its hand. Results show that the absence of gaze at the target affects joint action by reducing the prediction and coordination process (Khoramshahi, Shukla, Raffard, Bardy, & Billard, 2016; Volcic & Lappe, 2009). In the gestural imitation situation used, following the partner's gaze allows task planning to be shared and task sharing to be achieved. The idea here is to emphasize the place of the gaze in the joint action. The research cited concerns typical populations. There is a paucity of research studying the relationship between joint attention and joint activity in autism. This is not unrelated to the consensual demonstration of joint attention deficit in autism (Baird et al., 2000; Baron-Cohen, Allen, & Gillberg, 1992; Mundy, Sigman, & Kasari, 1990). If it is difficult to follow the other person's gaze and meet their interest in a target, joint motor action is likely made more uncertain. A study of the correlation between cooperative performance of children with ASDs and joint attention shows a significant relationship between the two abilities, and challenges the notion that cooperation is impossible without understanding the intent of the action (Colombi et al., 2009).

*2.1.b. The ability to plan one movement in relation to the movement of the other*

To achieve a successful motor action for two, the partner's movement characteristics should be integrated into his or her own movement planning. Several studies have addressed this issue. First, Rosenbaum and Jorgensen's study, for example, takes as an option the fact that movements are planned so that they are performed with maximum ease and stability in the final posture (Rosenbaum & Jorgensen, 1992). To achieve a comfortable final posture, the initial posture itself must be easy. Therefore, initial posture is a good indicator of effective planning. Poor initial placement in relation to an object will result in an uncomfortable final posture. A poor initial placement of one partner will result in an uncomfortable posture of the other and possible failure of the joint motor action. This final effect of initial posture has been replicated by several researchers in typical populations (Haggard, 1998; Cohen & Rosenbaum, 2004; Weigelt, Kunde, & Prinz, 2006). Gonzalez, Glazebrook, Studenka, & Lyons (2013) use this starting position paradigm to study planning abilities in autism (see fact sheet). Participants must first pick up, use or put down three objects that are more or less fixed in their function (including a small hammer). Then they must pass these objects to a partner who will put them down or use them. The comfort of the starting posture for the participant is measured when he or she uses the object himself or herself or when he or she has to pass the object to a partner. It also measures the partner's postural comfort when the object is passed to them (for example, can they use the hammer directly, or do they have to change their posture or grip). The results show that planning the movement to pass the object does not always result in a comfortable posture for the partner, and therefore there is no stable planning in participants with autism.

Several research findings support the idea that the more complex the motor tasks, the more difficult it is to plan (Dowd, McGinley, Taffe, & Rinehart, 2012; Glazebrook, Elliott, & Szatmari, 2008; Nazarali, Glazebrook, & Elliott, 2009). Cognitive elements must then be taken into account, as shown by Paulus' (2016; cf. fact sheet) experiments involving typical 3-, 5-, and 7-year-old children and adults. In this research, which uses a procedure close to that of Gonzalez and colleagues (2013), the idea was to pass a tool to someone so that he could open a mechanism placed vertically or horizontally. This task may seem simple and yet it involves being able to decentralize and take the perspective of the other, imagining that one is physically in his or her place. Furthermore, it must be understood that the other will have to carry out his part of the action on the basis of and in continuity with the action carried out by himself. The final goal is the result of the combination of two different sub-purposes: the first sub-purposes is to stretch the tool in a position adapted to the partner's sub-purposes which is to open a mechanism with the tool in the right orientation. There are two different roles with different objectives tending towards a common final goal. The driving coordination is here carried out in a complementarity of two different successive actions, the overall planning of which must be imagined. Such a two-role situation may explain the planning difficulties observed.

2.1.c. *Ability to coordinate roles*

This leads to the idea that inter-individual motor coordination may require more planning if it involves two different and successive motor actions representing two roles distributed among the partners. This type of task is often considered a cooperative task. Unfortunately, the definition of a collaborative task is not clear, despite some attempts such as that of Liebal and co-authors (Liebal, Colombi, Rogers, Warneken & Tomasello, 2008, see fact sheet). The authors' option is that assistance implies understanding the partner's goal, while cooperation requires moreover sharing the intention. They hypothesize that young children with ASDs should be able to help when the situation is simple (e.g., helping to pick something up) but that they should have difficulty cooperating given their lack of understanding of intentions. This is not what their results show, as children with ASDs are able to cooperate well. The authors note that their tasks focus on intention with respect to an object, which is more accessible in autism. The same authors use the same tasks, this time to analyze correlates of cooperation in Autism (Colombi et al., 2009). They propose to children with ASDs from 30 to 57 months of chronological age, and from 16 to 53 months of developmental age, four types of tasks that they all call cooperative but whose characteristics are distinct, as we will see. The first task, called elevator task, consists for one of the children to push a cylinder while the other one removes the object that comes out of the cylinder. There are indeed two different and successive roles for a common goal: to remove the object, but here the final goal merges with the sub-goal of the second child and the movements of each do not have to be adjusted to those of the other. Motor coordination is not in the foreground. A second task is of the same nature: from a system of double tubes mounted in parallel on a box, one of the children has to send a toy into the tube and the other has to catch it in the second tube.

More interesting is to analyze the other two tasks, still called cooperatives. In task 3, it is a matter of removing a toy from a tube 1m10 long and 10 cm in diameter that can only open if one pulls on each side at the same time, which is impossible on its own. In task 4, the two children form a trampoline by simultaneously lifting both ends of a cloth. In the latter two cases, the movements of the two children must be similar and simultaneous, the sub-goals are the same in order to achieve the final goal for which each is equally responsible: planning is much simpler. Are the movements easier? It is a pity that the authors did not attempt to address this question. But a theoretical framework from dynamical systems theory called 'embodied cooperation' has gathered data that may shed some light.

In the dynamic perspective where we study the physical elements of movement and not only the cognitive aspects, the motor constraints are the same, alone or in pairs, because they are anatomical constraints. However, performance differs, as new possibilities emerge between the two of them (Schmidt & Richardson, 2008). The paradigm of "embodied cooperation" (''embodied cooperation'') was created on the basis of the idea that the movements of another extend an individual's possibilities of action. The movement of the other offers new possibilities for our own actions, just as a tool offers more possibilities for action than our bare hands: we can speak of affordance. Affordance is a term that refers to the possibilities offered by the interaction between an individual and his or her physical environment (Gibson, 1977). Through cooperation, the social environment also allows new affordances for the motor skills of each individual. Cooperation in pair action is seen as a unique motor system with new capacities for social synergy (Marsh, Richardson, Baron, & Schmidt, 2006; Richardson, & Schmidt, 2009; Richardson, Marsh, & Baron, 2007). For example, the paradigm of Richardson and colleagues (Richardson, Marsh, & Baron, 2007) includes duets that must wear lightweight boards that are too long to be worn alone. Richardson and co-authors (Richardson et al., 2015) see body synchrony and cooperative action as a dyadic social reality based on similar or complementary motor patterns. The use of simple rhythmic movements makes it possible to examine the dynamics of interpersonal coordination, in phase or antiphase (Kelso, 1995). There are dynamic patterns included in joint action that are competitive, i.e. in antiphase. In this case the objective is individual. This is the difference with collaborative joint actions that have a common objective. A study in hyperscanning illustrates the brain effect of a community of objectives. The same duos are subjected to two types of procedure, either cooperative or competitive. In the cooperative situation, they must each press a key to a visual signal. If their answers are simultaneous, they receive one point, if they are staggered, they lose one point: the common goal is to gain points. In the competitive situation, it is a question of answering faster than one's partner to gain a point while the other loses a point: the objective is clearly individual. The interesting result is that only the cooperative situation induces coherence between the upper frontal cortex of the two people involved in the action: it is therefore the common objective that brings the partners together at the level of brain organization (Cui, Bryant & Reiss, 2011).

The idea that the body's effectors self-organize according to the dynamics of movement and are constrained by both anatomical data and what the environment offers, leads to the hypothesis of a spontaneous behavioral similarity between participants during a motor action in pairs. This leads us to analyze in particular situations of synchrony and similarity.

*2.1.d. Similarity and synchrony: the ability to couple the perception of the other's action and one's own action*

Neuromimicry theorized via mirror neurons (Rizzolatti & Craighero, 2004) has advanced interest in the social bases of motor skills by showing the cerebral relationship between observing someone doing an action and performing that action oneself (Decety & Grèzes, 1999). However, the reference to the other induced by the observation of the action remains internal to the individual. It is necessary that the perception-action coupling be joint to match the movements in the motor action to two. Crossed perception-action coupling, i.e., each one sees himself doing the same actions as the other, so that there is a direct social effect of the mirror system: immediate imitation can be considered as *shared motor action* (Nadel, 2016). Indeed, the similarity and synchronization of the actions performed presuppose the adaptation of one's motor skills to the motor skills of the other and provide the means to form common motor representations with others (Jeannerod, 2001).

The idea that synchronous imitation is the most basic socio-emotional connection situation is supported by studies of both typical adults (Chartrand & Bargh, 1999), typical preverbal children (Nadel & Baudonnière, 1982), and children with ASDs (Nadel, 2016). It provides the conditions under which an individual is best able to coordinate his or her movements with those of another. Richardson and his co-authors describe it as an integral part of embodied cooperation, in a rather global definition of cooperation: embodied cooperation, they say, implies that 'two people achieve a unity of action that integrates the participants and the common object' (Richardson et al., 2015). This unity of action is all the easier to achieve when one does the same thing at the same time. A minimal connection is realized through body synchrony.

Synchrony spontaneously organizes itself along with imitation: it is expressed at the cerebral level by synchronizations of the alpha mu rhythm in the centro-parietal zone of the mirror system of both partners during an imitation situation (Dumas, Nadel, Soussignan, Martinerie & Garnero, 2010). The literature shows that interpersonal synchrony provides an essential basis for social interaction. It increases social affiliation (Hove & Risert, 2009). Moreover, it has a brain effect similar to a puff of oxytocin, the attachment hormone, in autism (Delaveau, Arzounian, Rotgé, Nadel, & Fossati, 2015). Thus, we can consider the links between the achievement of a motor action and the development of positive social interaction.

Several researches use synchronous imitation as a paradigm to evaluate the effects of similarity and synchronization in collaborative motor skills. Thus, with typical populations, we measure the time delay between the trajectories of the hands of two partners who must imitate each other (Noy, Deckel & Alon, 2011).

Synchronous imitation is used in group psychomotricity for children with ASD, in the context of Exchange and Developmental Therapy (Barthélémy & Bonnet-Brilhaud, 2012; Le Menn-Tripi, 2013) or group psychomotor mediation (Bruandet, 2013). Each partner harmonizes his or her own movements to the overall movements: synchrony is treated as a motor tempo. These trainings resemble some of the tasks described by Colombi and colleagues (2009). It should be noted that the movements are free, as long as they respect a common tempo. On the contrary, situations in which a motor dialogue is necessary, such as pulling at each end of a cylinder so that it opens, or carrying a basin together, require more articulation between the movements of the two partners. We have called them collaborative, to distinguish them from situations where coordination involves different but complementary, synchronous or successive movements, more often called cooperative situations.

## **Autism and interactive technologies: elements for motor action in human-computer interaction (HCI)**

Echoing the previous part studying pair motor action from the point of view of the specificities of autism, this part is decomposed into two main sections: the first concerns human-machine devices for individual motor action and the second part deals with devices for dyadic human-machine interaction.

***Human-machine devices for individual motor action***

* 1. Commercial exergames: low-cost sensors and fun physical activity

Interactive sports applications (and associated sensors) have been developing in the video game industry for 10 years now. We find a wide variety of sensor systems such as the guitar in the game Guitar Hero, the interactive mat in the game Dance Dance Revolution or the Wiibalance force platform from Nintendo. The two biggest hits, Nintendo's Wiimote, which captures the movements of the hand holding a Wiimote controller, and Microsoft's Kinect, which captures body movements with a depth camera, have very quickly interested researchers. These are indeed sensors that are inexpensive for their quality and sold with playful content involving physical activity (i.e., exergames). In the current context where lack of physical activity is now identified as a health risk factor, various research studies have investigated the possibility of using these exergams to encourage older people to increase their physical activity (Brox, Luque, Evertsen, & Hernandez, 2011), or to combat obesity (Lyons, Tate, Komoski, Carr, & Ward, 2012; Staiano, Abraham, & Calvert, 2012; Lamboglia et al., 2013). In their review of the benefits of incorporating exergames into physical education classes, Staiano & Calvert (2011) found that children showed improvements in energy expenditure during class, frequency of daily physical activity, social interaction, and cognitive performance.

* 2. Whole body interaction for emotion recognition and body expression

It is at the level of sensory therapies that projects involving the body in its expressive dimension have emerged. The MEDIATE project is one of the first research projects proposing an immersive and multisensory environment aimed at developing a sense of control ("agency") as well as a sense of creative expression in children with ASD (Pares, Masri, Wolferen, & Creed, 2005). Based on pressure sensors on the ground under a carpet and on speech recognition, this device which uses the EyesWeb platform is equipped with two giant screens and a tactile printing area. The system adapts in real time to the actions of the child while avoiding repetitive behaviors. To do so, it modifies its interaction parameters according to what it detects of the child's activity, such as attracting to a different stimulus if repetitive behavior is detected. The main contribution of this project is twofold. First of all, it is one of the first interactive projects for children with ASD involving the whole body, demonstrating the technological feasibility of such a device. It also proposes a regulation system for children with ASD, adapting the complexity of the interaction (function of the types of action-stimulus associations) and the richness of the interaction (number of sensory modalities involved). This possibility of adaptation according to the behaviors of the child allows to preserve his commitment and to promote his autonomy in the installation. The MEDIATE project does not consider body movements in detail, making it impossible to work finely on issues such as body awareness or body expression. The SensoryPaint project (Ringland et al., 2014) proposes to fill this gap by presenting an interactive device for multimodal sensory intervention based on the capture of the child's silhouette, notably through the use of the Kinect depth camera. The child sees his silhouette on a screen whose color varies according to the distance from the screen, and can capture real balls which, once detected by the system, become virtual brushes. In the context of sensory therapies, this project explores the impact of such interaction (via his own silhouette on a screen) as well as the mode of interaction (free without a model or with a coloring guide on the screen) on the child's understanding of his body. The authors stress the importance of alternating guided and free interactions, of allowing participation in the practitioner's game and of not neglecting the fun aspect of the interaction. As we will see in section III, Nadel and Poli, for their part, used Kinect in 3 modalities to assess and train movement calibration and self-recognition in children with ASDs (Nadel and Poli, 2018).

***Human-machine devices for two-person motor action***

A number of currents in Human-Computer Interaction are interested in social interactions, and more specifically in dyadic interactions. The interactions supported by these devices can take multiple forms, synchronous or asynchronous, chaotic or structured, punctual or prolonged. In this project, we are interested in synchronous and dynamic interactions, that is to say, interactions that involve the movement of both persons of the dyad at the same time. Designed both to study and understand social interactions and to train social skills, the common point of the different devices described in this section is that they reduce the complexity of the dyadic interaction in order to make it understandable to children with ASD.

* 1. Tangible and tactile interaction for collaboration

1.1 Fostering social interaction with TUI (Tangible User Interface)

Tangible interaction (sometimes called "catchable interface") involves equipping a real object like a toy with computers so that it can be used, for example, by people with ASD interacting with a computer via that object (Fitzmaurice, Ishii, & Buxton, 1995). The physicality of this type of interface makes it particularly relevant for social and collaborative contexts, allowing for body engagement and shared controllers (Hornecker & Buur, 2006). For children, these interfaces are particularly playful and facilitate group interactions because of the multiple access points they provide (both in the way they interact with an object and in the subjective interpretation of that interaction; Fernaeus, Tholander, & Jonsson, 2008).

In the field of autism in children, therapies based on group play activities are developing, such as the use of LEGOs (Legoff & Sherman, 2006). This type of activity is particularly interesting for working on verbal and non-verbal communication, joint attention, collaborative problem-solving and turn-taking mechanisms. Above all, the activity is more accepted by children because it is based on manipulative games from everyday life. One of the key points of this type of therapy is to simplify one dimension of social interaction, for example here by explaining the roles of each child to facilitate interactions: one of the children is the engineer, the other is the builder, the third is the resource provider. Building on this interest in passive (i.e., non-interactive) building systems, Farr, Yuill, & Raffle (2010) study the benefits of using "augmented" games (also called Tangible User Interface, or TUI) in this type of therapy. Feedback mechanisms (visual, kinesthetic, or audio) make objects more interesting and increase the visibility of actions and their consequences for children with ASDs. In a first study, Farr et al. (2010) evaluate the use of a TUI called Topobo, a construction game with programmable kinetic memory (Raffle, Parkes, & Ishii, 2004). The dual interest of this game is that it is programmable, which encourages child engagement. The dynamic constructed creatures attract attention and provide opportunities for social interaction. In a second study, the same team sonically augmented a game with a castle and medieval figurines (Farr, Yuill, & Hinske, 2012). This is done by positioning the figurines using RFID (Radio Frequency IDentification) chips, which trigger pre-recorded sounds. Here too, allowing the child to configure the device himself (i.e., choose the sound content) is considered central: sounds increase the affordance and therefore the understanding of the system, personalization facilitates predictability. The Reactable interactive table was designed for live music performances (Jordà, Geiger, Alonso, & Kaltenbrunner, 2007). It allows mixing sounds via tangible controllers. An attempt has been made to apply it to social skills training, but the complexity of the system for both children and therapists seems to have limited its usefulness (Villafuerte, Markova, & Jorda, 2012). In summary, tangible interfaces have the potential to facilitate social interaction in group therapy but remain limited in the constraints they can impose on the situation, particularly in reducing social complexity and working on specific skills.

1.2 Interactive Tables and Virtual Environments for Collaboration

Unlike tangible interfaces, the collaboration devices described in this section are fully digital applications accessible via a screen. Since the interaction systems are therefore two-dimensional and virtual, it becomes easier for the researcher to constrain the rules of the game and to analyze the collaboration patterns that are being set up. For interactive tables and tablets, the digital application is presented on a shared touch screen (i.e., the participants are seated around the table) offering freedom in terms of social interaction. Whereas in the case of virtual environments for collaboration, each user is alone in front of a screen and can only interact with another person through the interface. In this case, it is the control of the interaction that is privileged by the researcher.

The interactive tables were developed with the objective of facilitating collaboration in a professional context, especially for creative problem-solving cases (Buisine, Besacier, Aoussat, & Vernier, 2012). Topics such as screen size and orientation, territoriality or interaction techniques have been studied in numerous studies. A key element of these devices is the possibility for the device to identify each user independently (i.e., identify the user for each finger touching the surface), as on the DiamondTouch table (Dietz & Leigh, 2001). Interactive table projects for children with ASDs have emerged quite quickly: they allow direct manipulation of digital objects with touch and avoid the fear of social isolation by offering group activities. Researchers are interested in designing applications that use different types of constraints or strategies to motivate or force collaborative activities among children (Battocchi et al., 2010; Boyd et al., 2015; Gal et al., 2009; Giusti, Zancanaro, Gal, & Weiss, 2011; Piper, O'Brien, Morris, & Winograd, 2006; Silva, Raposo, & Suplino, 2015). Structuring social interaction in this way makes it more affordable for children with ASDs because it is more predictable. The SIDES project uses the DiamondTouch table to develop a cooperative game for four players where children must build a path for a frog on water lilies together (Piper, O'Brien, Morris, & Winograd, 2006). The activity mobilizes the skills of negotiation, taking turns, active listening, and taking perspective. The interaction is structured in turns, with each child having his or her turn and buttons that only he or she can activate (which prevents another child from finishing another child's action). He decides by himself when to pass his turn via a specific button. Gal et al. (2009) develop the StoryTable, where dyads of children with ASDs are involved in collaborative storytelling. The children have to choose together the story elements such as the character and the background. Some actions can only be done by one child while others must be done jointly, for example, selecting the background (i.e., the button must be touched by two). This "touch together" constraint is an example of what Battocchi et al (2010) call the forced collaboration paradigm. They propose a collaborative puzzle task, a task that is more accessible to children with ASD because it relies on visuo-spatial skills. A dyad of children with ASD must complete a 16-piece puzzle using a series of cooperative gestures: touching together, moving together, letting go together. Sound feedback indicates whether the joint action is correct or not. The instruction tells the children that the goal is not speed, but that it is more important that they help each other and have fun. The authors indicate that these rules of forced collaboration induce social facilitation behaviors in children with ASDs. With the goal of integrating into cognitive behavioral therapy, Giusti, Zancanaro, Gal, & Weiss (2011) design a series of mini-games to develop three dimensions of collaboration: joint action, resource sharing, and mutual planning. For joint action, the two children must move a basket under trees together to receive falling apples. The difficulty may vary depending on the number of falling apples and their distance from the ground. Another version of the game implements different roles for each child: one child touches stars to make them fall while the other moves the basket to catch them. Finally, for the last game, the dyad has to rebuild a bridge but each child has access to only part of the necessary parts. The authors highlight the importance of considering the practitioner's role in the interaction involving two children with ASDs: a system of touch validation by the practitioner allows the practitioner to maintain control over the course of the dyadic activity (e.g., by tempering the actions of an impulsive child). This three-dimensional breakdown of collaboration is echoed by Boyd et al. (2015) in a study of dyadic use of a commercial game on Ipad (i.e., Zody). For the authors, design choices can encourage three levels of social relationships: sharing resources and roles encourages a sense of belonging to a group, coordinated actions encourage collaborative relationships, and sharing experiences encourages friendly relationships. Silva, Raposo, & Suplino (2015) propose another taxonomy of collaboration pattern along a continuum from the simplest to the most complex: passive sharing (complementary roles and resource exchanges); active sharing (information exchange and the need for communication); joint performance (simultaneous actions and collaborative activity); unrestricted interactions (free interaction). The authors' idea is to gradually encourage the child to collaborate starting from a very structured interaction. It should be noted that although the authors speak of simultaneous action, the children's actions remain complementary, thus preserving the roles of each.

Some projects are taking the decision to further reduce the complexity of social interaction by proposing remote collaborative games: we talk about virtual collaboration environment. The other advantage of these projects is that they are based on consumer computers potentially facilitating their implementation in the field. Wade et al (2017) present a collaborative pong game for children with ASD called DOSE (Dyad-Operated Social Encouragement). The game has four different modes: a "single" mode for practice, a "dyad against artificial intelligence" mode where the two children share the keyboard to control the bar (forced collaboration paradigm), a "rally" mode where the two children each have a bar and must make as many passes as possible, and finally a "competition" mode. The difficulty is managed by changing the size of the ball, the size of the bar and the level of artificial intelligence (i.e., by playing on the probability that the virtual opponent will miss the ball). The authors point out the importance of recording quantitative data during the game phases in order to propose different metrics that can be used by practitioners. However, the data presented in this project remain limited: the application gives access to the dyad score, the number of words per minute of the dyad, the word difference between the children of the dyad and the score difference between the children of the dyad. Having dyadic interaction at a distance allows control over what each member of the dyad perceives, providing further opportunities for interdependence in the context of collaborative play. In the CoMove application (Zhang et al., 2018), the dyad of children with ASD must complete a tangram (a puzzle of seven pieces forming a square). Three modes are implemented: a turn-based game where each child takes turns doing an action, an information-sharing game where one of the children does not have the colors of the pieces and must therefore exchange with his or her partner, and a collaborative game where the children must move the pieces simultaneously. A recording of quantitative data is made: start and end time of the game, frequency of successes, information on the movement of the pieces and audio data of verbal communication. The measures of children's progress presented in this article are essentially based on an a posteriori annotation of verbal communication (e.g., number of questions, number of positive reinforcements).

Through these projects, the importance of breaking down what makes a collaboration work to better adjust the level of complexity of the task becomes apparent. However, the models behind these decompositions remain arbitrary and a better theoretical anchoring would allow a better articulation with existing therapies. We also find the central role of the practitioner who must be able to regulate the interaction as well as collect data at the end of the intervention. On this last point, the metrics for evaluating collaboration are still very limited. Finally, although quite often implemented, the action of moving a virtual object in pairs has not been studied in detail: research quantifies the number of times the joint action is carried out without looking at how it is carried out.

2. Anthropomorphic agents for non-verbal interaction

A virtual agent is an animated character (2D or 3D) whose behaviors (facial expressions, body movement, gaze, ...) are controllable. They can therefore be used to design animated videos that will then be selected and displayed during the interaction, or even react in real time to the user's behaviors during the interaction. Depending on the computer platforms and research prototypes used, these virtual agents can be more or less expressive, and more or less interactive in real time. They are particularly relevant for the simulation and training of social skills. Indeed, animated virtual agents have multiple advantages over pre-recorded videos of people. Their non-verbal expressions (e.g. facial expressions, looks, postures) can be controlled more finely. When they are truly interactive (and therefore not just pre-recorded videos), they can be used to train continuous and finely tuned behaviors (e.g. eye tracking as we will see later). They are thus seen as a good compromise between experimental control and ecological validity to study and simulate social interactions using verbal and non-verbal behaviors. Some of these prototypes have been designed for and evaluated by people with ASD. Other prototypes have been developed for neurotypical users, for example, to train individuals to conduct job interviews or public speaking. However, we think it is useful to consider them here because they train basic skills (such as smiling at the right time, paying attention to others) that are useful for children and adolescents with ASD, whether in social interactions in a school setting or in helping some adults with ASD go to job interviews, or in conducting quality social interactions in their daily lives.

The use of virtual agents in the literature can be seen from two angles: 1) to allow for specialized experimental studies aimed at better understanding certain specific deficits of people with ASD (often without a rich situational context), and 2) at a more macroscopic level, to design and evaluate virtual training systems for social skills (often in one or more specific interaction situations).

Many studies do not allow a real learning of dyadic social interaction skills because the user's behaviors do not impact the virtual agent's behaviors: it is just a non-interactive presentation with a virtual agent and a user (Grynszpan, Martin & Nadel, 2008). These real-time dynamic adjustment skills during social interactions must be trained precisely in people with ASD. In the remainder of this section, we describe research prototypes in which the user's behavior impacts the social behaviors of the virtual agent during a dyadic interaction. A review of broader issues including the uses of virtual agents in the case of non-interactive presentation with a virtual agent and a user, or the use of several virtual agents at the same time can be found in Martin's article (Martin, 2018).

In learning situations, interaction with peers has shown positive results (Bowman-Perrott et al., 2013). A system using this track allows an autistic child to play with physical objects such as the building blocks of a children's home, while interacting with a virtual child about the toy (Tartaro, Cassell, Ratz, Lira, & Nanclares-Nogués, 2014). Even if physical objects are not interactive, they allow social interactions to be anchored in the physical and real world.

## Autism and Individual and Pair Motor Action Training by interactive technologies

The mobilization of both motor and social skills in commercial exergames has attracted the interest of researchers in the field of ASD. For example, Guitar Hero is a game in which the console controller is a toy guitar. The main goal of the authors is to train children in various leisure-related skills to facilitate social integration (Blum-Dimaya, Reeve, & Hoch, 2010). Although not involving the whole body, this study paves the way for the use of commercial games with physical activities for therapy applications in a playful setting. With the aim of designing software dedicated to autism, the impact of four Kinect Sports games on attentional skills was studied (Bartoli, Corradi, Garzotto, & Valoriani, 2013). The authors underline the questions that the use of this type of device with children with ASD raises: will the child understand an "intangible" interaction (i.e., a non-contact movement having an effect)? Indeed, commercial exergames are still largely unsuitable for training children with ASD. On the motor level, the gestures required by the game are not necessarily relevant, on the sensory level, these games offer a large number of potential sources of distraction, and finally, on the social level, these games rely on social codes that are not acquired by children with ASDs (Edwards, Jeffrey, May, Rinehart, & Barnett, 2017). Devices better adapted to this population have then emerged.

The possibility of capturing a person's body movements via various sensors was explored early on with the idea of providing an aid to motor drive. Virtual PAT was one of the first systems to use video-based motion capture for personalized feedback on performance (Davis & Bobick, 1998). But it is since the development of low-cost motion sensors that projects for designing systems capable of adapting in real time have been developed for the general public. The majority of these projects are based on Kinect-type depth cameras, because they allow the recognition of different parts of the body. YouMove is an interactive system inspired by dance studio mirrors (Anderson, Grossman, Matejka, & Fitzmaurice, 2013). The application of this system allows a trainer to record a movement, edit the capture and define important parameters for evaluation, and then a student to train on this movement. By comparing the differences in body position between the coach and the student during the movement, the device can provide accurate feedback on the student's errors. Where YouMove provides an a posteriori evaluation, MotionMA also provides real-time feedback on the movement to be performed via the display of arrows indicating the change of position to be made (Velloso, Bulling, & Gellersen, 2013). These low-cost technologies have also been used in therapeutic contexts, such as for the early diagnosis of spinal muscular atrophy (Chen et al., 2017), with precision limited to the centimeter and constraints of postures to enable capture (being from the front, clothing close to the body, without occulting objects). We therefore remain on interesting technologies for certain motor tasks, involving gross rather than fine motor skills, often to be used in addition to expert opinion. For children, learning motor skills through the use of these technologies is often done through the development of a game. Thus, a game is proposed where the child takes the role of a soccer goalkeeper: thanks to the capture of his or her movements, the system displays his or her hands in a soccer cage with the task of catching the balls pulled by a virtual character (Hsiao & Chen, 2016). One of the interests of these approaches is to combine motor learning with other types of learning, as with the Kinems Suite, which combines cognitive and academic training (Kourakli et al., 2017). In this type of learning context, the limited accuracy of the sensor is less impacting. It is at the level of the selection of tasks and movements as well as the design of the game mode and the learning process that the stakes are high. One of the consequences is that very few of these games use quantified movement information for the analysis of the child's performance, limited to a count of the number of gestures for example. In the case of children with motor coordination problems, hand stability during tasks is studied to assess children's progress (Kourakli et al. , 2017). Based on their experience deploying Kinect commercial games in children's settings with TSA, Bartoli, Garzotto, Gelsomini, Oliveto, & Valoriani (2014) propose a set of design principles that inform the development of three Kinect-based mini-games. Among the 23 principles, one part is specific to a type of skill (motor, cognitive, or social). Twelve general principles are common to all types of applications and inform the design process: one game per child (customization); evolving tasks; a single goal; visual instructions; minimalist graphics; clear audio; dynamic stimuli; and use of avatars. The first game, "Bubble Game", aims to improve the precision of the child's movements and visuomotor coordination by offering the child to catch bubbles via his/her articulated avatar. The second game, "Space Game", works on selective and sustained attention: the child must move a "pointer avatar" (with his hand, it is not an articulated avatar) to avoid falling objects. Finally, the third game, "Shape Game", focuses on the child's awareness of his or her body through a silhouette game: the child must imitate a silhouette with his or her own body. The strong point of this project is the possibility for the clinician to customize each game for each child, for example by varying the number of objects, the active body parts or the background of the game.

In the same spirit but with a more complete development, Pictogram Room was conceived as an educational video game where the child with TSA interacts in the game via his avatar directly linked to his own movements (Herrera et al., 2012). To facilitate the child's recognition of his avatar, a minimalist representation was chosen, in "wire" and mono-color. This software proposes as a pedagogical objective to train body language, attention and imitation. The 80 games are organized in 4 categories: "the body", "postures", "signal" and "imitate". This wide variety of tasks is intended to target specific skills to be developed in the child (for example, the activity "Showing through the eyes" allows to work on joint attention in the "signal" section), as well as to set up personalized programs (cf. for a detailed description Herrera & Perez-Fuster, 2018, which is the subject of a fact sheet).

Several therapies exploit this application or part of it: thus Nadel and Poli have developed an evaluation and training of self-knowledge by exploiting several resources of Kinect (body appearing in reflection, contour or avatar). They also use virtual objects from the Pictogram Room application to train the intentional calibration of movement (Nadel and Poli, 2018).

# Synthesis

The objective of the research "Software for training combined with collaborative social interaction and motor learning in Autism Spectrum Disorder" is to produce an affordable and reproducible application to train children with ASD to collaborate on tasks involving motor coordination between two individuals with the goal of performing together an action that is impossible to perform alone.

This synthesis of the literature review is produced from the selected corpus of documents (commented general bibliography presented below). It consists of highlighting existing knowledge, at the international level and from a social point of view, on the identified themes. The synthesis is based on documents in French and English from studies conducted in various countries.

This synthesis note briefly summarizes the main work on the concepts of motor coordination and joint activities, considering the social capacities involved at the same time postural and motor capacities. The note also summarizes the devices resulting from new technologies that allow online training, notably by creating partner avatars of children with ASD.

The literature teaches us that interindividual motor coordination presupposes, in order to be realized, good individual capacities of postural balance, in that this balance of each one ensures the stabilization of the joints, the calibration of the movement and the planning of the initial posture leading to a comfortable posture of the partner to achieve his goal in the common action. In addition to these individual motor skills, social and cognitive skills are necessary: being able to follow the other's gaze in order to anticipate his movement towards the target, being able to plan his action in reference to the other's movement, being able to take the other's perspective, being able to assume a different role from his partner, being able to imitate synchronously.

By identifying the different types of procedure used for pair motor actions, we were able to distinguish four types of pair movements: simultaneous but free movements leading towards a common goal, simultaneous but complementary movements with different motor roles for the same goal, successive complementary movements where the sub-purpose is different for each partner, simultaneous and similar movements where the goal is the same for each (imitation is facilitating here).

New technologies contribute to an analysis of the skills required in collaborative motor skills and their training. The main technologies used to improve motor skills are based on depth cameras with Kinect type motion sensors because they allow discrimination between body parts. For example, it is possible to compare the movements of the dance teacher with those of the student, with real-time feedback on the movement to be performed. Low-cost interactive sports applications (and associated sensors) are an opportunity to work on motor collaboration by developing knowledge of the body through multimodal sensory information. Virtual agents add the controllable interactive element that is necessary to train motor collaboration in a controlled way before performing it between two humans. Interactive table devices allow to study the mechanisms of collaboration between two people. However, although quite often implemented, the action of moving a virtual object on a table between two people has not been studied in detail: research quantifies the frequency of success of the task without analyzing its processes. Our contribution is therefore original and should allow us to make progress in the analysis of the prerequisites of a motor collaboration and in taking them into account during training.

Existing therapies dedicated to motor training in ASD allow us to build on existing devices such as the Kinect platform, and to train children to use an avatar through Pictogram Room (Herrera et al., 2012; Herrera & Perez-Fuster, 2018). In addition, our team of autism specialists has developed a tool for assessing and training self-recognition and movement calibration (Nadel & Poli, 2018). This tool will be very useful for setting up the population of children with ASD testing the training software. However, these software and technological tools are concerned with training individual motor skills. In order to move on to 2-way motor training, we benefit from the expertise of our team of computer scientists regarding interactive avatars (Martin, 2018). Two types of avatars are under construction: one helping two-person motor action by adjusting to the child's movements, and the other not helping, so that it is the child who must adjust to the avatar's movements. Finally, our expertise in imitation in autism (Nadel, 2014) allows us to anticipate the final phase of the work: once trained in motor collaboration with the avatar, the children will collaborate with each other, adjusting their gestures to the other's model.

In conclusion, this synthesis constitutes a review of relevant literature in the context of the project to create "Software for training combined with collaborative social interaction and motor learning in autism spectrum disorder".

These different studies clearly show:

* The need to consider two types of two-pronged driving action: 1) actions involving a different and complementary role for the two partners, and 2) actions involving the same role for both partners. Only this second type of two-way motor action implies the simultaneity of the movements of both partners.
* The role of a two-way motor action as a means of establishing social cohesion with a partner.
* The importance of social skills such as imitation, synchrony, joint attention, to develop a joint action.
* In addition to social skills, the importance of cognitive skills such as anticipation of the other's action, representation of common action sequences, overall action planning.
* At a more basic level, the importance of recognizing one's movements in a relationship between vision and proprioception ('I feel I am doing what I see me doing').

However, these studies also highlight certain aspects that can serve as directions for future research. Thus, the question remains to distinguish between motor actions in pairs in which the movements of each partner are free, although coordinated, from those in which a motor dialogue is necessary because the action can only be carried out through an exact simultaneity of the same movement by both partners: thus, the movements are constrained not only by the action to be carried out but also by the movement of the other. This may seem a disadvantage. Yet the similarity of anatomies that respond similarly to the natural laws of the environment facilitates imitation and engenders synchrony. Therefore, it may be that motor collaborations of simultaneous and similar type are the easiest to achieve. It would be interesting to test this hypothesis in order to present to children with ASD the easiest situations of actions in pairs, i.e. those that can be achieved by imitating the other.

The use of new technologies to implement, assess and train individual motor skills is developing rapidly. Robotics, digital equipment (boards and tablets), and virtual reality offer tools that are increasingly adapted to the specificities of autism. Virtual reality, when it uses tangible objects, i.e. objects that have a weight and thus produce a sensation of effort to move, is adapted by its realism to groups of non-verbal people with ASD. The construction of interactive avatars is a specialty of our team of computer scientists. It is adapted here to the scenarios proposed by our team of autism specialists.

The literature shows that in MMI, motor collaboration is evaluated primarily as a collective performance achieved by the dyad or group, rather than as a means of analyzing the motor skills of each individual and their coordination. The development of our technological tools is aimed here at analyzing the means of the children to carry out a collaborative task requiring them to consider the other. It constitutes the basis for the realization of the training software.

The existing interactive technologies underlying the Kinect platform allow us to place our goal of creating training software in an already formatted framework, such as Pictogram Room. However, even if Pictogram Room addresses the problem of collaboration, it does so on the basis of perception (learning joint attention, informing by looking, adjusting one's posture to a calibration produced by the avatar and for which the consequences are visual). Through the use of tangible objects, we aim to train children with ASD by using motor skills in action together.

# Reading cards

The research presented below is extracted from the main bibliography, each of which has been summarized in a reading sheet. These searches were deemed to be particularly relevant to the Resource Centre's criteria. The criteria are as follow:

* The connection between research results and the implementation of the principles of the International Convention on the Rights of Persons with Disabilities[[2]](#footnote-2),
* Collaboration between researchers and actors in the field,
* The identification of results that are applied or applicable to improve the quality of life of people with disabilities.
* The use of research methods.

Each reading sheet contains a link allowing access to the documents and to the notice on the documentary base of the Centre Ressources Recherche Appliquée et Handicap.

## Autism and motor action in pairs

* Fournier, K.A., Hass, C.J., Naik, S.K., Lodha, N., Cauraugh, J.H. (2010). **Motor coordination in autism spectrum disorder: A synthesis and meta-analysis**. Journal of Autism and Developmental Disorders. 40, 1227-1240.

**Keywords**: Autism spectrum disorder, motor coordination and deficits, meta-analysis

**Abstract**

Are motor coordination deficits a cardinal feature of Autism Spectrum Disorder (ASD)? Database searches identified 83 ASD studies that focused on deficits in motor coordination, arm movement, balance, or postural stability. Data retrieval involved intergroup comparisons between ASDs and typically developing children (N=1). Rigorous meta-analytic techniques including random effects models, publication bias, false positive analysis, and moderator variable analyses determined a standard effect size of mean difference equal to 1.20 (ES=0.144; p<0.0001; Z=10.49). This large effect indicates deficits in motor coordination for many behaviors in the ASD groups. The overall results describe motor coordination deficits as present in all forms of autism, and thus as a cardinal characteristic of autism.

**Comment**

This very rigorous meta-analysis extracts data from 51 studies all evaluating postural stability, balance, walking and arm movements in groups diagnosed with autism compared to typical groups without neurological impairment. The analysis ranges from 18 months to 33 years of age. It gathers a population of 1238 persons with autism matched on chronological age to 3017 typical persons. Seven variables are analyzed: motor reaction time, accuracy of movement, adaptation rate, locomotion velocity, pressure span, balance stability and standard motor scales (including M-ABC or Vineland Motor Standard Scores).

The results are very clear, despite the heterogeneity of evaluation methods. They show a wide prevalence of gross motor problems in the autistic population, and a specificity of motor coordination deficits, particularly concerning postural control and mobility.

This article is very useful because it accurately describes the type of motor difficulties most often encountered in autism, although they are rarely specified. However, postural control is an important factor of concentration and attention, and thus plays not only on motor performance but also on cognitive and social performance.

* Gonzalez, D.A., Glazebrook, C.M., Studenka, B.E., and Lyons, J. (2013). **Motor interactions with another person: Do individuals with Autism Spectrum Disorder plan?** Frontiers in Integrative Neuroscience, *7,* 1-9. DOI :10.3389/fnint.2013.00023

**Key Words**: Autism spectrum disorder, motor skills, movement planning, theory of mind, joint action

**Abstract**

Interpersonal motor interactions (joint actions) occur daily. In joint action situations, typically developing children consider the end goal and adjust their movement to fit the other person. The planning processes required for joint action may be difficult for individuals with Autism Spectrum Disorder (ASD) given their known difficulties with theory of mind tasks and motor activities. The purpose of this experiment was to determine whether individuals with ASDs can behave in a way that achieves a comfortable end state in joint action situations, as typical individuals do. Participants had to pass, place, or use three common tools: a small wooden hammer, a stick, or a calculator. The choice of these tools was related to their degree of affluence (the physical characteristics likely to elicit their own use), ranging from direct affluence for the hammer to indirect affluence for the calculator. Participants had to pass the equipment on to the partner who placed or used it. Variables of interest were the comfortable or uncomfortable orientation of the grip at the beginning and end of the movement for the participant and partner depending on the task, and the side through which the object was placed or passed. Some individuals with ASDs maximized the comfort of their partner's initial state by personally adopting an uncomfortable posture. That said, their performance was more variable than that of typical individuals who systematically passed objects in a way that allowed their partner a comfortable grasping posture. Thus, the movement planning processes used to prepare to pass an object are not systematic in people with ASDs. The new task described in this article could serve as a basis for testing the important aspect of the link between motor performance and more complex social and communicative behaviors.

**Comment**

This article gives us an interesting basis for testing the ability of people with ASD to plan their movement in relation to others. It answers the question of whether they are able to facilitate the taking of the other and whether they can consider what the other will do with the object. In the article, adults are involved, but this simple task could be used as a test for children with ASD in an even simpler version that involves moving from one object to another. In this way we can see if the child considers the other - which is social -, and is able to adapt his or her movement according to it - which is motor -. In this way the motor basis of social interaction can be measured.

* Herrera, G., and Pérez-Fuster, P. (2018). **Pictogram Room: Its effectiveness in autism spectrum disorder (ASD).** Childhood, 70.1, 31-50.

**Key Words**: Revision, Autism, Support, Technology, Efficiency, Augmented Reality.

**Abstract**

Various research studies have investigated the biological movement perception of individuals with Autism Spectrum Disorder (ASD), indicating their difficulties in understanding and using body language to communicate. Augmented reality technologies offer an opportunity for visual and musical supports to intervene on these skills in ASDs. This article provides a description of the scientific basis of the Pictogram Room tool along with a review of two investigative studies about its effectiveness. The first of these studies evaluates the impact of Pictogram Room on improving the sensory and motor skills of a group of ten children with ASD. The second study analyzes its effectiveness in improving joint attention in six children with ASD. Both studies indicate positive results for the effectiveness of Pictogram Room depending on initial expectations. In conclusion, research regarding the understanding and use of body language in ASDs highlights the need for tools for their management. The positive results of the first studies on the effectiveness of Pictogram Room presage a future in which these technologies will form part of the usual therapeutic proposals.

**Comment**

This article presents the pictogram room software, a technological tool created with the aim of training many abilities that are known to be deficient in autism. It focuses on non-verbal communication and the skills involved such as body language, joint attention, imitation, facial expressions and gestures. Currently, this tool is available in French, English and Spanish and has more than 11,000 users. Pictogram Room uses a camera projector system to capture the user's image and reproduce it by enhancing it with a series of graphic elements. Optionally, this interaction can take place in groups (between a child with ASD and a playmate or tutor). The camera projector system used is Microsoft Kinect. Pictogram room has 80 games organized in four categories: Body, Postures, Signaling and Imitating. Two categories are particularly important to facilitate motor coordination: Body and postures. With the body category, the user can gradually increase his attention to the different parts of the body of the character who represents him as if facing a mirror. With the postures category, the user can acquire a better knowledge of his body with each use and learn to differentiate between different postures. In the category concerning imitation, most of the games aim to work on the visuomotor aspects, possibly related to rhythm. These elements make pictogram room a very efficient technological tool to train basic motor skills necessary to carry out collaborative actions in pairs.

* Liebal, K., Colombi, C., Rogers, S.J., Warneken, F., & Tomasello, M. (2008). **Help and cooperation in children with autism**. Journal of Autism and Developmental Disorders, 38.

**Key Words**: Help, cooperation, autism, understanding goals, sharing goals

**Abstract**

Help and cooperation are central elements of social life. Here we report on two studies exploring these social behaviors in children with autism and children with delay. In the first study, both groups of children helped the experimenter achieve his goal. In the second study, both groups of children cooperated with an adult but few children with autism were able to complete the tasks. When the adult stopped interacting at some point, the children with autism made fewer attempts to reconnect, indicating that they had not formed a shared goal/intention with the adult. These findings are discussed in terms of cognitive and motivational abilities and propensities for social behaviors.

**Comment**

In this article, the authors describe the human specificity of cooperation. They relate it to the ability to share goals and intentions. They situate the emergence of understanding of other people's goals and intentions in babies around the age of one year, soon followed by the ability to share goals and intentions. At 18 months, young children are able to help pick up an object that has fallen inadvertently. What about autism? Depending on the area, autism is more or less affected by a difficulty in understanding the goals of others. For example, children with autism can understand intentions when it comes to actions on objects. The idea behind the article is that children with autism are able to help because in this case the goal is committed, they just need to understand it, whereas they should have difficulty cooperating because in this case both people need to coordinate their behavior for a common goal. In fact in this study the children with autism did quite well with cooperation because it was a very concrete and simple goal to share. The notion of coordination emerges in reference to a goal that must be shared: this is the very important lesson of this article, which focuses mainly on cognitive functions.

* Nadel, J. and Poli, G. (2018). **Evaluating and training body awareness in autism via kinect and Pictogram Room.** Childhood, 70, 1, 51-64.

**Key Words**: Knowledge of the body, Recognition of being imitated, Autism Spectrum Disorder, Kinect Platform.

**Abstract**

This article presents the use of a video game platform to assess the level of body image representation in young non-verbal children with ASD. The stimuli are the reflection of the real body projected on the wall, the gray or colored silhouette unrelated to the child's clothing, the small wire avatar. The assessment is based on criteria from the developmental literature using mirror reflection and vertical shadowing. Based on the results of the evaluation, a play therapy can be developed with the aim of moving the children towards more elaborate levels of body representation, possibly to an allocentric conception of

the situation in the surrounding space, both physical and social.

**Comment**

The Pictogram Room application is very effective in developing the motor and social skills of people with ASD. However, it requires a level of representation that allows you to identify yourself in a small avatar. For children who have not achieved this level of self-representation, it is important to identify where they are in terms of self-recognition and how to develop it. This is what the study proposes, which distinguishes 3 levels of self-recognition. The recognition of its reflection is made in reference to the figurative details which characterizes the individual (his hair, his nose, his clothing...), it is followed by a recognition of his silhouette made possible by the synchrony of the movements. Once this recognition is acquired, we can propose the recognition of oneself in its exoskeleton (avatar): synchrony is also the determining element complicated here by a representation without with the real body, and thus symbolic. Once this representation is acquired, the Pictogram Room application becomes affordable. It is therefore a very useful training tool prior to the use of Pictogram Room for non-verbal children who have not acquired a symbolic representation of themselves.

* Paulus, M. (2016). **The development of action planning in a context of joint action.** Developmental Psychology, 52,

**Key Words**: Cognitive Development, Action Control, Joint Action, Action Planning

**Abstract**

The ability to do an action jointly with another person is a fundamental necessity in social life. This study examines the development of action planning in the context of joint action. In four experiments, children aged 3, 5, and 7, as well as a group of adults (n=196), interacted with another person to operate a new device. Their task was to provide the experimenter with a tool that she could grasp and insert in a particular direction. We looked to see if the participants planned their grip and hold in such a way that the partner could manoeuvre the tool well, thus anticipating the final state of the joint activity. We found that 3-year-olds did not adjust their behavior to accommodate the other's action and did not increase their performance after multiple attempts. The 5- and 7-year-olds tended to initially plan their actions on an egocentric basis but improved their joint action performance as the trials progressed. Adult participants showed joint action planning from the beginning. It should be noted that 3- and 5-year-olds were able to plan effectively when acting alone on the device. However, first-hand experience with the task did not facilitate their performance during subsequent joint action. Taken as a whole, the study provides information on current psychological approaches and ontogenetic origins of joint action in childhood.

**Comment**

This article reports on the development of capacities to take the partner into account when planning a joint action. Although it focuses on typically developing children and not on children with ASD, what it tells us about the difficulties and progress of young children between the ages of 3 and 7 is very useful in understanding what may be involved in carrying out joint action for children with ASD, especially if their cognitive performance is poor. Indeed, the article emphasizes the cognitive elements involved in this very simple task that may seem essentially motor. Giving a tool to someone to open a mechanism placed vertically or horizontally actually requires much more than the simple movement of stretching the object. First of all, one must be able to decentralize oneself and take the perspective of the other, imagining being physically in his or her place: one must be allocentric. In addition, it is necessary to understand that the other will have to carry out his part of the action on the basis of and in continuity with that carried out by oneself. The author points out that the ability to take the perspective of the other is already well developed at the age of 4-5 years, but that putting it into direct practice is not without effort and continues to develop until adolescence. This is evidenced by the fact that 5-year-olds show a marked improvement in planning for joint action once they have completed the entire task on their own. However, it is likely that it is not just a matter of taking the other person's perspective: completing the entire task helps to summarize the motor sequences that need to be followed. An important part of planning is to visualize the future steps of an action.

Another element to be considered concerns the representation of the effects of an action: one can imagine the effects of handing the tool to the adult without considering what the adult will do with it and therefore without adjusting the presentation of the object for its future use. On the other hand, older children see their own action as part of the general plan, it is a sub-goal and not the final goal, so they have a co-representation of the goal they share with the adult. But for a long time, it will take inhibitory control to prevent the representation of one's own goal in joint action from taking precedence over the joint final goal.

So what do these findings tell us about joint action in children with ASD?

It should be noted that the child with ASD easily takes hold of tense objects, or even removes objects from your hands, but does not give easily: is this an indication of a difficulty in conceiving the place of the other in an action on an object? Moreover, some of them abandon the objects in the course of an action: the objects are not thrown but fall down. This strange behavior could well be explained by a lack of planning of the action and representation of its effects: the action runs short because it is not finalized. How can these difficulties be improved? Carrying out the action has an effect on its representation, so it is important to multiply the opportunities to exercise and then to have to represent the exercise again.

* Romero, V, Kallen, R., Riley, M., and Richardson, M. (2015). **Can discontinuous joint action be synergistic? Study of the stabilization of manual inter-individual coordination.** Journal of Experimental Psychology, Human Perception and Performance, Volume 41.

**Key words**: joint action, interpersonal coordination, motor synergy, motor control

**Abstract**

The human perceptual-motor system is closely coupled to the physical and informational dynamics of a task's environment. These dynamics operate to constrain the highest dimensional level of the human motion system to basic and task-specific dimensional synergies: functional groupings of structural elements are temporarily constrained to act as a single coordinated unit. The objective of this study was to determine whether synergistic processes operate when individuals co-act to perform a discontinuous joint task. Pairs of participants sat next to each other and each used one arm to complete a scoring task. Using MCU analysis for the first time with discontinuous joint action, the variance structure of the joint angle was used to determine whether there was a synergistic organization of the degrees of freedom employed at the intra- and inter-individual level. The results show that the motor actions carried out by the co-actors were organized synergistically at the intra- and inter-individual levels. Even more, the inter-individual synergy was significantly stronger than the intra-individual synergies. Therefore, the results clearly show that individuals who carry out a joint action can organize themselves to temporarily form a single synergistic system of 2 persons during the realization of a discontinuous joint action.

**Comment**

The article is very specialized and can be considered difficult to read. Indeed, there are many details about the apparatus and the method of collecting many tests to make an estimate of the diversity of movements performed to reach the target: the less varied the movements are, the more synergy there is between the two arms of two different people. The procedure is sophisticated and uses trackers and markers on the shoulders and arms to measure joint angles. However, the idea of the article and its results are very interesting and deserve to be described to fully understand what interpersonal motor coordination means in a pair action. In this study, pairs of people are sitting side by side: one holds a target with his lower left hand and the other holds a pointer with his right hand. The pointer must reach the target. The question is: will each partner move his or her arm independently, or will one partner's arm move in relation to the other's arm? There is a common goal: the pointer must hit the target. The one holding the target can consider the position of the pointer and the one holding the pointer can adjust to the position of the target. The results are astonishing: everything happens as if these two people have only two arms between them, a left arm holding the target and a right arm holding the pointer. These two arms, which do not belong to the same person, are more in synergy than when each person uses both arms to perform the same action of hitting a target with a pointer. In this article, these are typical adults, not people with ASD. But we can retain the interest which there can be to train people with ASD on this model of action with two: it is necessary to have the same goal and to adapt its movement to the movement of the other: what is more social in the concreteness of an action?

## Technologies for Motor Collaborative Actions

* Bartoli, L., Garzotto, F., Gelsomini, M., Oliveto, L., & Valoriani, M. (2014). **Designing and Evaluating Touchless Playful Interaction for ASD Children**. In Proceedings of the 2014 *Conference on Interaction Design and Children* (p. 17-26). New York, NY, USA: ACM. https://doi.org/10.1145/2593968.2593976

**Key Words**: Autistic children, touchless interaction based on movement, therapy

**Abstract**

Few existing studies explore motion-based and touchless applications for children with autism and explore the design issues and benefits they can provide. This paper reports a set of structured design principles that integrates our experience gained through empirical studies and collaborations with therapeutic centers. These heuristic propositions informed the design of three touchless games that were then evaluated in a controlled study involving autistic children in the therapeutic center. Our results confirm the potential of motion-based and touchless games in technology-enhanced interventions for this specific group.

**Comment**

The work of Laura Bartoli and her colleagues is interesting in that it articulates the exploration of the potential benefits of commercial exergames with the design of new exergames adapted to the learning of certain skills for autistic children. In a previous paper, the researchers were able to have children play Kinect games selected by therapists (from the MS Kinect Sports and MS Rabbids Alive & Kicking packages) and conduct assessments of attentional and emotional skills (observations, clinical measures, etc.). Beyond this therapeutic evaluation, human-computer interaction researchers were able to gain a more detailed understanding of how autistic children appropriate games and their mechanisms, and thus identify the limits of commercial games. The paper presented here takes stock of these remarks by formalizing a list of principles for the design of adapted exergames. On the basis of these principles, three mini-games are developed and then evaluated, thus illustrating the contribution of these "guidelines".

The establishment of such lists is an important step in the understanding of a subject by human-computer interaction researchers in order to design for that subject. It is not a checklist to be followed to the letter, but rather points of attention to be questioned when designing. The list proposed here is divided into two parts: a general part (common to all exergames) and a part specifying the purpose of the exergame (motor, cognitive or social learning). The general principles include elements relating to the specificity of each child (the importance of customization and the evolution of the game), remarks on the complexity and richness of the game (having only one goal, having clear sound feedback and minimalist graphics) or on considering the interaction with the practitioner (by facilitating transitions between games, as well as the repeatability and predictability of a task).

For all three games, ("Bubble Game", "Space Game" and "Shape Game"), the common strength is the ability for the clinician to customize each game for each child, for example by varying the number of objects, active body parts or the background of the game. It should be noted that the authors used the same measures of progression for the games they designed as for the commercial exergames: the results show a better progression for the suitably designed game.

* Battocchi, A., Ben-Sasson, A., Esposito, G., Gal, E., Pianesi, F., Tomasini, D., Venuti, P., Weiss, P., Zancanaro, M. (2010). **Collaborative puzzle game: a tabletop interface for fostering collaborative skills in children with autism spectrum disorders**. *Journal of Assistive Technologies*, 4(1), 4-13. https://doi.org/10.5042/jat.2010.0040

**Key Words**: Interactive table, autism spectrum, collaboration, social skills.

**Abstract**

Interactive tables are a new class of technology particularly appropriate for the use of collocated collaboration. The Collaboration Puzzle Game is an interactive table activity designed to develop collaborative skills in children with autism. The game features an interaction rule called Forced Collaboration; in order to move the pieces of the puzzle, they must be touched and dragged simultaneously by both players. Two studies were conducted to test the effect of this interaction rule on collaboration. In the first study, 70 typical boys were tested in dyads to characterize how they respond to forced collaboration; in the second study, 16 boys with autism were tested in dyads. The results suggest that the interaction rule generally has a positive effect on collaboration and is associated with more complex interactions. For children with autism, forced collaboration was effective in triggering behaviors associated with task coordination and negotiation.

**Comment**

Research on interactive table design to encourage and coach social interaction in children with autism is very interesting to have first insights on "how to design for pair action" (which here is not motor). The paper presented here is interesting for several reasons. First of all it proposes an interactive tabletop puzzle game which, to be realized, forces children to do actions together. The authors thus introduce a new approach, or rather a rule of interaction, which they call "forced collaboration". Thus, to move a piece of the puzzle, the two children in the dyad must touch the piece at the same time, move the piece together, and then release the piece together. If one of these three actions is not well coordinated, the piece comes to a stop and a negative sound feedback tells the children that the action is over. In the field of human-machine interaction, formalizing and studying rules of interaction is a way of producing knowledge about "how to design an interactive system". The puzzle has 16 pieces.

Note that this paper is the first to propose a puzzle task: the authors consider this task more accessible and rewarding for autistic children because it is based on visuo-spatial skills. An evaluation including seventy typical boys on one side and sixteen autistic boys on the other side compares the social interactions during the puzzle game in the case where forced collaboration is implemented and, in the case, where it is not. Interestingly, while the paradigm of forced collaboration has little impact on typical children, it does induce in children with autism an increase in "coordination behavior", i.e., behaviors designed to facilitate interaction between two people to complete the task.

* Bernardini, S., Porayska-Pomsta, K., & Smith, T. J. (2014). **ECHOES: An intelligent serious game for fostering social communication in children with autism**. *Information Sciences*, 264, 41-60. https://doi.org/10.1016/j.ins.2013.10.027

**Keywords**: Virtual social partner, pedagogical agent, autonomous intelligent agent, artificial intelligent planning, autism, social communication.

**Abstract**

This paper presents ECHOES, a serious game built to help children with Autism Spectrum Disorder practice communication skills. We focus on the design and implementation of interactive learning activities, which take place in a two-dimensional sensory garden, and with an autonomous virtual agent who acts as a credible social partner. The activities and the agent are based on good practice principles and user feedback. Specification principles are given to build a socially competent autonomous agent that facilitates learning in this context. We present experimental results on the effectiveness of the agent based on an evaluation of the ECHOES platform, showing encouraging trends for a number of children.

**Comment**

The authors explain how they adapted the SCERTS model of human-to-human social communication to design an animated agent and educational activities using a participatory approach and pre-testing with children with ASD. ECHOES aims to train social skills (defined by the authors as "Social communication involves the ability to coordinate and share attention, intentions, and emotions with others as well as the capacity for engaging in reciprocal interaction by understanding and using verbal and non-verbal means.)

The authors describe existing work aimed at improving language, affective or interactive skills as well as virtual agents that are rarely autonomous. On the contrary, in coherence with the SCERTS framework, ECHOES includes an agent that can be pro-active, reactive and have social skills. SCERTS targets 3 areas of competence: social communication, emotion regulation and transactional support. It targets 3 developmental levels: social partner, language partner and conversational partner (the latter is not considered in ECHOES).

ECHOES uses a large multi-touch screen with eye tracking. The twelve pedagogical activities focus on two components of social communication: joint attention and symbolic use. A virtual garden is displayed with an animated agent and objects that react to the child's gestures on the touch screen. Some activities are oriented towards a precise and clear goal (sorting balls by color). Other activities are more pretexts for cooperation and exchanges.

The agent follows the FATIMA architecture to simulate cognitive and emotional skills and also uses a component managing the pedagogical goals and a model of the child. Machine learning is also used to predict the child's engagement based on the touches he makes on the touch screen. The participatory approach for the graphic design of the agent's appearance is described. Its behaviors (gestural and facial animations, verbalizations) are as follows: responding to requests for interaction, initiating interaction, managing speech turns.

An experiment carried out with 29 children in 5 schools is described. The children's social skills were documented before and after the sessions with ECHOES. The results are described with regard to the responses to the initiations to interact made by the animated agent and the initiations made by the child. While at the beginning, the child initiates less interaction with the virtual agent than with another person, this difference disappears during the sessions. According to the authors, the agent is credible because he is able to respond in real time to the child's actions and to behave autonomously, which allows the degree of predictability to vary.

* Farr, W., Yuill, N., & Raffle, H. (2010). **Social benefits of a tangible user interface for children with Autistic Spectrum Conditions**. *Autism*, 14(3), 237-252. https://doi.org/10.1177/1362361310363280

**Key words**: Autism, interaction, play, tangible.

**Abstract**

Tangible user interfaces integrate computational technologies into catchable objects. This study evaluates the potential of Topobo, a construction toy with programmable movements that facilitates social interaction for children with autism spectrum disorders. Groups of either typical or autistic children participated in several play sessions with Topobo and LEGOs. We recorded sequences of different categories of play during these sessions. For participants in both groups, we observed more forms of social play with Topobo than with LEGO. More cases of solitaire gambling were observed with LEGO and more cases of parallel gambling were observed with Topobo. Topobo also generated more cooperative play in typical children. Finally, we observed differences in play sequences between typical children and children with autism, so we discuss how these different elements might produce specific play patterns in these two groups.

**Comment**

In the field of autism in children, therapies based on group play activities are developing, such as the use of LEGOs (Legoff & Sherman, 2006). This type of activity is particularly interesting for working on verbal and non-verbal communication, joint attention, collaborative problem-solving and turn-taking mechanisms. Above all, the activity is more accepted by children because it is based on manipulative games from everyday life. Based on this interest in passive (i.e., non-interactive) building systems, the authors of the paper in this fact sheet study the benefits of using "augmented" games (also called Tangible User Interface, or TUI) in this type of therapy. Interactive feedback mechanisms (visual, kinesthetic or audio) make objects more interesting and increase the visibility of actions and their consequences for children with ASD. This paper is a first study that evaluates the use of a TUI called Topobo, a construction game with programmable kinetic memory by comparing it to the practice of LEGO therapy. The double interest of this game is that it is programmable, which encourages the child's commitment. The dynamic constructed creatures attract attention and provide opportunities for social interaction.

This paper is one of the first to focus on the interest of tangible interfaces for social interaction. Other researchers have instead explored the potential of tangible interfaces as facilitating pretend play. An evaluation based on the observation of six children with autism indicates that TUI Topobo offers more opportunity for social interaction than LEGO play.

* Ringland, K. E., Zalapa, R., Neal, M., Escobedo, L., Tentori, M., & Hayes, G. R. (2014). **SensoryPaint: A Multimodal Sensory Intervention for Children with Neurodevelopmental Disorders**. In Proceedings of the 2014 ACM *International Joint Conference on Pervasive and Ubiquitous Computing* (p. 873-884). New York, NY, USA: ACM. https://doi.org/10.1145/2632048.2632065

**Keywords**: Widescreen, natural user interface, autism, child-computer interaction.

**Abstract**

Natural, multimodal user interfaces offer an innovative approach to sensory integration therapies. We designed and developed SensoryPaint, a multimodal system that allows users to paint on a widescreen using physical objects, body-based interactions, and interactive audio. We evaluated the impact of SensoryPaint through two studies: a laboratory study with 15 children with neurodevelopmental disorders during which they were able to interact with the system for 1 hour, and a deployment study with 4 autistic children during which the system was integrated into existing daily sensory therapy sessions. Our results show that multimodal widescreen displays using whole body interaction combined with tangible and audio interaction balance the children's attention between their own bodies and sensory stimuli, enhancing existing therapies and promoting socialization. These findings have implications for the design of other ubiquitous computing systems for children with neurodevelopmental disorders and for their integration within existing therapies.

**Comment**

Researchers in human-computer interaction have also explored the design of interactive games involving the whole body in the context of sensory therapies. Here the focus is less on the training of specific motor or social skills and more on body expression and the relationship to the child's body. The SensoryPaint project presented in this paper proposes an interactive device for multimodal sensory intervention based on the capture of the child's silhouette, notably through the use of the Kinect depth camera. The child sees on a screen his silhouette whose color varies according to the distance from the screen, and can capture real balls which, once detected by the system, become virtual brushes. In the context of sensory therapies, this project explores the impact of such interaction (via his own silhouette on a screen) as well as the mode of interaction (free without a model or with a coloring guide on the screen) on the child's understanding of his body. Two qualitative assessments (first 15 children with ASD for a one-time laboratory interaction and then a 4-week deployment with 4 children in sensory therapy) are presented. The authors emphasize the importance of alternating guided and free interactions, allowing participation in the practitioner's play, and not neglecting the fun aspect of the interaction.

* Zhang, L., Fu, Q., Swanson, A., Weitlauf, A., Warren, Z., & Sarkar, N. (2018). **Design and Evaluation of a Collaborative Virtual Environment (CoMove) for Autism Spectrum Disorder Intervention**. *ACM Transactions on Accessible Computing*, 11(2), 11:1-11:22. https://doi.org/10.1145/3209687

**Keywords**: Learning environments, autism, collaborative computing.

**Abstract**

The spectrum of autistic disorder is a neurodevelopmental disorder characterized in part by significant deficits in communication and social interaction. A collaborative virtual environment, which is a distributed, virtual space for multiple users interacting together and with virtual elements, enables flexible, safe, and peer-based social interactions. In this paper, we present the design of a collaborative virtual environment called CoMove, with the main objectives of measuring and potentially improving the collaborative interactions and verbal communication of children with autism when they play collaborative puzzle games with typical child partners from distributed locations. CoMove has two distinctive features: first, the ability to promote important collaborative behaviors (including information sharing, sequential interactions, and simultaneous interactions) and provide real-time feedback based on player performance, as well as an objective way to measure and index important aspects of collaboration and verbal communication during system interaction. A feasibility study with 14 dyads - 7 typical child dyads with autistic children and 7 typical child dyads - was initially conducted to test the feasibility of CoMove. The results of the study validate the feasibility of the system and suggest its potential for indexing important aspects of collaboration and verbal communication.

**Comment**

Some human-computer interaction projects take the side of reducing the complexity of social interaction for training purposes by proposing remote collaborative games: we talk about virtual collaboration environment. Having a dyadic interaction at a distance allows to control what each member of the dyad perceives, which offers other possibilities of interdependence in the context of a collaborative game. The other advantage of these projects is that they are based on consumer computers, potentially facilitating their implementation in the field. In the CoMove application presented in this paper, the dyad of children with TSA has to perform a tangram (a puzzle of seven pieces forming a square). Three modes are implemented: a turn-based game where each child takes turns to do one action in turn, an information-sharing game where one of the children does not have the colors of the pieces and must therefore exchange with his partner, and a collaborative game where the children must move the pieces simultaneously. A recording of quantitative data is made: time of the beginning and end of the game, frequency of successes, information on the movement of the pieces and audio data of verbal communications. The measures of children's progress presented in this article are essentially based on an a posteriori annotation of verbal communication (e.g., number of questions, number of positive reinforcements). In this very recent paper, the importance given by the authors to the implementation of data collection testifies to the community's understanding of human-computer interaction and the appropriation by practitioners of the devices designed. The proposed evaluation is a feasibility study, to verify that the functionalities of the system are valid for dyads of autistic children.

# Commented general bibliography

## Autism and motor action in pairs

In this part, we present a bibliography of 52 documents listing the main works on autism, its diagnosis, its specificities, notably motor and social, motor collaboration, joint action.

The title of the reference contains a link to the full document when it is available for free or for a fee.

The link of the references that have been the subject of a reading sheet refers to the complete record of the documentary base of the Centre Ressources Recherche Appliquée et Handicap.

**References**

* American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.). Washington, DC: Author. https://doi.org/10.1176/appi.books.9780890425596.dsm01

The manual is the authoritative guide to the diagnosis of mental disorders. The 2013 version brings a significant change in the classification of what was previously described as pervasive developmental disorders, including autism. The Autism Spectrum Disorder category now includes previously separate syndromes such as Asperger's, and is part of a broader set of neurodevelopmental disorders.

* Baird, G., Charman, T., Baron-Cohen, S., Cox, A., Swettenham, J., Wheelwright, S., & Drew, A. (2000). A screening instrument for autism at 18 month of age. *Journal of the American Academy of Child and Adolescent Psychiatry*, *39*, 694-702. http://doi.org/10.1097/00004583-200006000-00007

This article presents a detailed version of the CHAT as a screening (not diagnostic) instrument for autism at 18 months.

* Baron-Cohen, S., Allen, J., & Gillberg, C. (1992). Can Autism be Detected at 18 Months? The Needle, the Haystack, and the CHAT. *British Journal of Psychiatry, 161*, 6, 839-843. http://doi.org/doi:10.1192/bjp.161.6.839

This article is the first to introduce the 18-month screening tool for early signs of autism (CHAT), focusing on the role of joint attention as a predictor.

* Bullinger, A. (2015). *The sensory-motor development of children and their avatars. The space of gravity, the premature baby and the child with PDD*, vol. II. Ramonville Saint-Agne: Érès.

In this book, the author develops his theory of motricity on the basis of the importance of postural stability in the face of gravity.

* Barthélémy, C., & Bonnet-Brilhaud, F. (2012). *Autism from childhood to adulthood*. Paris: Flammarion.

This book takes up the principle of Exchange and Developmental Therapy by integrating recent knowledge in neurodevelopment and its positive results.

* Bruandet, F. (2013). Psychomotor-mediated group: Practical experience in CAMPS. In J. Perrin & T. Maffre (eds), *Autisme et psychomotricité* (pp.345-359). Brussels: de Boeck.

This chapter provides examples of the use of motor coordination in group psychomotor skills.

* Bryson, S.E., Zwaigenbaum, L., Brian, J., Roberts, W., Szatmari, P., Rombough, V., & McDermott, C. (2007). A prospective case series of high risk infants who developed autism. *Journal of Autism and Developmental Disorders*, *37*, 1, 12-24. http://doi.org/10.1007/s10803-006-0328-2

This is a study designed to identify early signs of autism in very young siblings of children with autism.

* Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of Personality and Social Psychology*, 76, 893-910.

The article emphasizes being imitated as creating or strengthening social bonds.

* Cohen, R. G., & ROSENBAUM, D. A. (2004). Where grasps are made reveals how grasps are planned: generation and recall of motor plans*. Experimental Brain Research*, 157, 4, 486-95. http://doi.org/10.1007/s00221-004-1862-9

The article shows that the way gripping is carried out is indicative of its planning.

* Colombi, C., Liebal, K., Tomasello, m., Young, G., Warneken, F., & Rogers, S. (2009). Examining correlates of cooperation in autism. *Autism*, 13, 2, 143-163.

The purpose of the study was to examine the contribution of three early social abilities, imitation, joint attention and understanding of intentionality in the cooperative ability in autism.

* David, F. J., Baranek, G. T., Wiesen, C., Miao, A. F., & Thorpe, D. E. (2012). Coordination of precision grip in 2-6 years-old children with autism spectrum disorders compared to children developing typically and children with developmental disabilities. *Frontiers in Integrative Neuroscience*, *6*, 1-13. http://doi.org/10.3389/fnint.2012.00122

The conclusion of the study suggests a delay in motor coordination in autism rather than a specific disorder when comparing the three populations of children (typical, with ASD and developmentally delayed).

* Dowd, A. M., McGinley, J. L., Taffe, J. R., & Rinehart N. J. (2012). Do planning and visual integration difficulties underpin motor dysfunction in autism? A kinematic study of young children with autism. *Journal of Autism and Developmental Disorders, 42,* 8, 1539-1548. http://doi.org/10.1007/s10803-011-1385-8

A kinematic study shows that planning difficulties intervene in the motor dysfunction of autism.

* Dawson, G., Webb, S., & McPartland, J. (2005). Understanding the nature of face processing impairment in autism. *Developmental Neuropsychology*, *27*, 3, 403-424. http://doi.org/10.1207/s15326942dn2703\_6

The article shows the nature of the facial processing deficit in autism.

* Decety, J. & Grèzes, J. (1999). Neural mechanisms subserving the perception of human actions. *Trends In Cognitive Sciences, 3,* 5, 172-178.

This review article describes the neural mechanisms underlying the perception of human actions.

* Delaveau, P., Arzounian, D., Rotgé, J.-Y., Nadel, J., & Fossati, P. (2015). Does imitation act as an oxytocin nebulizer in autism spectrum disorder? *Brain*, *138*, 7, 1-4. http://doi.org/10.1093/brain/awv060

The Functional MRI (fMRI) study of young adults with ASD is a before-and-after mimicked study. The fMRI after mimicking shows activation of the right lower insula similar to that induced by nebulization of oxytocin, the attachment hormone. This shows the positive social effect of mimicry.

* Dumas, G., Nadel, J., Soussignan, R., Martinerie, J., & Garnero, L. (2010). Interbrain synchronization during social interaction. *PlosOne*, *5*, 8. https://doi.org/10.1371/journal.pone.0012166

This article uses the hyperscanning technique which allows to record two brains simultaneously. It shows that the cerebral effect of imitating each other in synchrony is the synchronization of certain brain rhythms in the brains of both partners.

* Fournier, K. A., Hass, C. J., Naik, S. K., Lodha, N., & Cauraugh, J. H. (2010). Motor coordination in autism spectrum disorders: A synthesis and meta-analysis. *Journal of Autism and Developmental Disorders*, *40*, 10, 1227-1240. http://doi.org/10.1007/s10803-010-0981-3

This article is summarized and commented in a documentary file.

* Gepner, B. (2014). *Autism: slowing down the external world, calming down the internal world.* Paris: Odile Jacob.

As the title indicates, the author develops his theory that visual inputs receive specific treatment in autism that is improved in some cases by slowing down the visual or auditory presentation. Free online software can be used with the enclosed instructions for use.

* Gibson, J. J. (1977). The Theory of Affordances. In R. Shaw & J. Bransford (eds), *Perceiving, Acting, and Knowing: Toward an Ecological Psychology* (pp. 67-82). Hillsdale, NJ: Lawrence Erlbaum.

This well-known chapter explains the theory according to which objects offer coherent action capabilities, called affordances, with their specific characteristics.

* Glazebrook, C. M., Elliott, D., Szatmari, P. (2008). How do individuals with autism plan their movements? *Journal of Autism and Developmental Disorders, 38,* 1, 114-126. http://doi.org/10.1007/s10803-007-0369-1

The study shows how difficult it is for children with ASD to plan their movement.

* Gonzalez, D. A., Glazebrook, C. M., Studenka, B. E., & Lyons, J. (2013). Motor interactions with another person: do individuals with Autism Spectrum Disorder plan ahead? *Frontiers in Integrative Neuroscience*, *7*, 1-9. http://doi.org/10.3389/fnint.2013.00023

The article is summarized and commented in a documentary file.

* Haggard, P. (1998). Planning of action sequences. *Acta Psychologica, 99*, 2, 201-215.

http://dx.doi.org/10.1016/S0001-6918(98)00011-0

The article analyzes the complex planning related to actions involving the sequencing of several sequences in typical individuals.

* Henderson, S.E., Sugden, D.A. (1992). *Movement Assessment Battery for children: Manual*. London: Psychological Corporation.

This manual presents a battery of tests of the child's motor skills.

* Hove, M., & Risert, J. (2009). It's all in the timing : interpersonal synchrony increases affiliation. *Social cognition, 27*, 6, 949-960. https://doi.org/10.1521/soco.2009.27.6.949

The article shows the role of interpersonal synchrony in the feeling of social closeness.

* Jeannerod, M. (2001). Neural simulation of action : A unifying mechanism for motor cognition, *Neuroimage*, *14*, 1-2, 103-109. https://doi.org/10.1006/nimg.2001.0832

This article synthesizes the major discoveries related to the perception-action coupling in which Jeannerod is an important actor. He emphasizes here the importance of action simulation, which he has shown to generate the same cerebral activations as action production.

* Kelso, J. (1995). *Dynamic patterns*. Cambridge, MA: MIT Press.

In this classic work, the author develops his conception of dynamic systems theory from the point of view of the overall relations between dynamic systems of different levels.

* Khoramshahi, M., Shukla, A., Raffard, S., Bardy, B. G., & Billard, A. (2016). Role of gaze cues in interpersonal motor coordination: Towards higher affiliation in human-robot interaction. *PLoS ONE*, *11*(6), 1-22. http://doi.org/10.1371/journal.pone.0156874

This paper shows the importance of the gaze target in interpersonal motor coordination using an imitative interaction between a robot and a human.

* Le Menn-Tripi, C. (2013). Psychomotor assessment of children with autism spectrum disorders. In J. Perrin & T. Maffre (eds), *Autisme et psychomotricité* (pp.345-359). Brussels: de Boeck University.

This chapter shows the use of imitation in psychomotor assessment.

* Liebal, K., Colombi, C., Rogers, S.J., Warneken, F., & Tomasello, M. (2008). Help and cooperation in children with autism. Journal of Autism and Developmental Disorders, 38.

The article shows the importance of goal sharing to achieve collaborative action.

* Marsh, K. L., Richardson, M. J., Baron, R. M., & Schmidt, R. C. (2006). Contrasting Approaches to Perceiving and Acting With Others. *Ecological Psychology, 18*, 1, 1-37. https://doi.org/10.1207/s15326969eco1801\_1

This article discusses an ecological and dynamic perspective of interpersonal coordination where the simple spontaneous coordination of rhythmic movements gives rise to feelings of social closeness and affinity.

* Marsh, K., Richardson, M., & Schmidt, R. (2009). Social Connection Through Joint Action and Interpersonal Coordination, *Topics in Cognitive Science*, *1*, 2, 320-339. http://doi.org/10.1111/j.1756-8765.2009.01022.

This paper proposes a theoretical and empirical synthesis of the embodied and contextualized cooperation option showing that it creates social bonds.

* McDonald, M.M., Lord, C., & Ulrich, D. (2013). The relationships of motor skills and social communicative skills in school-aged children with autism spectrum disorder. *Adapted Physical Activity Quarterly, 30*, 3, 271-282.

The article shows the relationships between motor and communicative abilities of school-aged children with autism spectrum disorders.

* Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. *Journal of Autism and Developmenal Disorders*, *20*, 1, 115-128.

This classic longitudinal study shows the difficulties of access to joint attention in children with autism, and the links with language development.

* Nadel, J. (2016). *Imitating to grow: Baby and child development with autism* (2nd ed. ). Paris : Dunod.

This book presents the role of imitation in the development of non-verbal communication and social interactions during typical development and in the Autism Spectrum Disorder (ASD).

* Nadel, J., & Baudonnière, P-M. (1982). The social function of reciprocal imitation in 2-year-old peers. *International Journal of Behavioral Development*, 5, 95-109.

The article shows for the first time at the international level that imitation has a communicative function in preverbal children.

* Nadel, J., & Poli, G. (2018). Evaluating and training body awareness in autism via kinect and pictogram room. *Childhood,* 1, 51-64.

The article presents a self-recognition assessment and therapy tool based on the use of the Kinect platform.

* Nazarali, N., Glazebrook, C., & Elliot, D. (2009). Movement planning and reprogramming in individuals with autism. *Journal of Autism and Developmenal Disorders*, *39*, 1401-1411. https://doi.org/10.1007/s10803-009-0756-x

The article examines the ability of people with autism to reprogram the planning of a failed movement.

* Noy, L., Dekel, M., & Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *Proceedings of the National Academy of Sciences, 108*, 52, 20947-20952. https://doi.org/10.1073/pnas.1108155108

The authors use imitation in synchrony to study the dynamics between two people who improvise movements together.

* Ozonoff, S., Young, G. S., Goldring, S., Greiss-Hess, L., Herrera, A. M., Steele, J., Macari, S., Hepburn, S., & Rogers, S. J. (2008). Gross motor development, movement anormalities and early identification of autism. *Journal of autism and Developmental Disorders, 38*, 4, 644-656. <https://doi.org/10.1007/s10803-007-0430-0>

The article focuses on gross motor skills and its abnormalities in the early identification of autism.

* Paulus, M. (2016). The development of action planning in a context of joint action. Developmental Psychology, 52.

This study examines the development of action planning in the context of joint action. The task was to provide the experimenter with a tool that she could grasp and insert in a particular direction. The results show the importance of anticipating the other's gesture with reference to the final objective. It is particularly interesting to take into account in the study of motor collaboration.

* Richardson, M. J., Marsh, K. L., & Baron, R. M. (2007). Judging and Actualizing Intrapersonal and Interpersonal Affordances. *Journal of Experimental Psychology, 33*, 4, 845-859. <https://doi.org/10.1037/0096-1523.33.4.845>

The article compares the affordances that emerge in individual or inter-individual situations to show that the movements of the other enriches the repertoire of possibilities in the motor field.

* Richardson, M. J., Harrison, S. J., Kallen, R. W., Walton, A., Eiler, B. A., Saltzman, E. & Schmidt, R. C. (2015). Self-Organized Complementary Joint Action: Behavioral Dynamics of an Interpersonal Collision-Avoidance Task. *Journal of Experimental Psychology, 41*, 3, 665-679. [http://dx.doi.org/10.1037/xhp0000041](http://psycnet.apa.org/doi/10.1037/xhp0000041)

The presented study shows that the dynamic coordination processes underlying simple motor synchronization (such as rhythmic movements) may also underlie more complex and goal-oriented pair actions, and may participate in the spontaneous emergence of complementary roles (such as asymmetric coordination of movement patterns) during a pair action.

* Rinehart, N., Bradshaw, J., Brereton, A., & Tonge, B. (2001). Movement preparation in high functioning autism and Asperger disorder. *Journal of Autism and Developmental Disorders, 31*, 1, 79-88. https://doi.org/10.1023/A:1005617831035.

The article shows that the movement preparation deficit in high-functioning autism concerns the cognitive organization of motor sequences in the service of a finalized action.

* Rizzolatti, G., & Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience*, *27*, 169-192. <https://doi.org/10.1146/annurev.neuro.27.070203.144230>

This is one of the many articles by the Rizzolatti team demonstrating the existence of a mirror neuronal system that generates cerebral equivalences between doing and observing doing.

* Romero, V, Kallen, R., Riley, M., and Richardson, M. (2015). Can discontinuous joint action be synergistic? Study of the stabilization of manual inter-individual coordination. Journal of Experimental Psychology, Human Perception and Performance, Volume 41.

The study describes a driving collaboration between pairs of people who have a common goal to achieve but with different and complementary roles. It is about adapting one's movement to the movement of the other. The results are for typical adults, but this is exactly the type of skill our software would like to train children with ASD. The task can inspire trainings.

* Rosenbaum, D. A., & Jorgensen M. J. (1992). Planning macroscopic aspects of manual control. *Human Movement Science, 11*, 1-2, 61-69. <https://doi.org/10.1016/0167-9457(92)90050-L>

The study shows that the initial posture for performing an action predicts the final posture: if the initial posture is comfortable, the final posture will be comfortable, showing that there is planning for the entire process.

* Schmitz, C., Martin, N., & Assaiante, C. (2002). Building anticipatory postural adjustment during childhood: a kinematic and electromyographic analysis of unloading in children from 4 to 8 years of age. *Experimental Brain Research*, *142*, 3, 354-364. <https://doi.org/10.1007/s00221-001-0910-y>

This article examines the postural adjustments required for load bearing in typical children between 4 and 8 years of age. The data are kinematic and electromyographic.

* Schmidt, R.C., & Richardson, M.J. (2008). Dynamics of Interpersonal Coordination. In A. Fuchs & V.K. Jirsa (eds), *Coordination: Neural, Behavioral and Social Dynamics* (pp 281-308). Berlin: Springer. <https://doi.org/10.1007/978-3-540-74479-5_14>

The chapter presents an option from dynamical systems theory showing that the physiological constraints of degrees of freedom being the same, movement in pairs is no more constrained than individual movement and even allows for the creation of new performances.

* Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action : bodies and minds moving together. *Trends in Cognitive Science*, *10*, 2, 70-76. https://doi.org/10.1016/j.tics.2005.12.009.

This review article shows the importance of cognitive motor factors in joint action.

* Volcic, R., & Lappe, M. (2009). Predictive eye movements in gaze and action observation. *Journal of Vision*, *9*, 436. <https://doi.org/10.1167/9.8.436>

The article shows that eye movements are predictive in observing the action and direction of gaze.

* Weigelt, M., Kunde, W., & Prinz, W. (2006). End-state comfort in bimanual object manipulation. *Experimental psychology, 53*, 2, 143-148. <https://doi.org/10.1027/1618-3169.53.2.143>

The article experiments the effect of the initial posture in the comfort of the arrival posture in a two-handed manipulation situation.

* Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International Journal of Developmental Neuroscience*, *23*, 2-3, 143-152. <https://doi.org/10.1016/j.ijdevneu.2004.05.001->

The much-quoted article represents the largest prospective study of younger siblings of autistic children to date. It allows the first signs to be documented well before a diagnosis is made at a later date.

## Technologies for Motor Collaborative Actions

In this section, we present a bibliography of 40 documents listing the main works related to the use of new technologies in the field of motricity.

**References**

* Anderson, F., Grossman, T., Matejka, J., & Fitzmaurice, G. (2013). YouMove: Enhancing Movement Training with an Augmented Reality Mirror. In Proceedings of the 26th Annual *ACM Symposium on User Interface Software and Technology* (p. 311-320). New York, NY, USA: ACM. <https://doi.org/10.1145/2501988.2502045>

YouMove is an interactive system inspired by dance studio mirrors. The application of this system allows a trainer to record a movement, edit the capture and define the important parameters for evaluation, and then a student to train on this movement.

* Bartoli, L., Corradi, C., Garzotto, F., & Valoriani, M. (2013). Exploring Motion-based Touchless Games for Autistic Children's Learning. In Proceedings of the 12th *International Conference on Interaction Design and Children* (p. 102-111). New York, NY, USA: ACM. <https://doi.org/10.1145/2485760.2485774>

With the aim of designing software dedicated to autism, the impact of four Kinect Sports games on attentional skills was studied in this project.

* Bartoli, L., Garzotto, F., Gelsomini, M., Oliveto, L., & Valoriani, M. (2014). Designing and Evaluating Touchless Playful Interaction for ASD Children. In Proceedings of the 2014 *Conference on Interaction Design and Children* (p. 17-26). New York, NY, USA: ACM. <https://doi.org/10.1145/2593968.2593976>

The authors present a list of recommendations from their practice of designing motion-based interactive games. These recommendations are classified into 4 sections: general, motor skills, cognitive skills and social skills. A quantitative evaluation of 3 2-dimensional games based on these principles is proposed: a game where the child must catch bubbles, a game where the child must avoid objects and a game where the child must imitate a posture. The small number of participants (9 children) limits the scope of the conclusions.

* Battocchi, A., Ben-Sasson, A., Esposito, G., Gal, E., Pianesi, F., Tomasini, D., ... Zancanaro, M. (2010). Collaborative puzzle game: a tabletop interface for fostering collaborative skills in children with autism spectrum disorders. *Journal of Assistive Technologies*, 4(1), 4-13. <https://doi.org/10.5042/jat.2010.0040>

The collaborative puzzle game presented by the authors introduces the concept of "forced collaboration" as a rule of interaction. In this multi-user tactile device, a puzzle piece can only be moved if two children touch it at the same time, forcing joint action to complete the task. A one-time evaluation with 16 children with ASD shows that the forced collaboration device induces more coordination behaviors.

* Bernardini, S., Porayska-Pomsta, K., & Smith, T. J. (2014). ECHOES: An intelligent serious game for fostering social communication in children with autism. *Information Sciences*, 264, 41-60. <https://doi.org/10.1016/j.ins.2013.10.027>

This article describes the design and evaluation of a serious game called ECHOES involving a virtual agent with social skills (speech turns, initiation of interaction, facial expressions and gestures). An evaluation is described with 29 participants. Videos of the interactions with the virtual agent were manually annotated. The article emphasizes the design and the need for the virtual agent to be a credible social agent. The heterogeneity of the participants (age and school of origin) explains, according to the authors, the lack of significant results for all the participants.

* Blum-Dimaya, A., Reeve, S. A., Reeve, K. F., & Hoch, H. (2010). Teaching Children with Autism to Play a Video Game Using Activity Schedules and Game-Embedded Simultaneous Video Modeling. *Education and Treatment of Children*, 33(3), 351-370. <https://doi.org/10.1353/etc.0.0103>

The main objective of the authors is to train children in various leisure-related skills in order to facilitate social integration. The game Guitar Hero is chosen, a game for which the console controller is a toy guitar.

* Bowman-Perrott, L., Davis, H., Vannest, K., Williams, L., Greenwood, C., & Parker, R. (2013). Academic Benefits of Peer Tutoring: A Meta-Analytic Review of Single-Case Research. *School Psychology Review*, 42(1), 39-55.

Journal article analyzing the academic benefits of peer tutoring.

* Boyd, L. E., Ringland, K. E., Haimson, O. L., Fernandez, H., Bistarkey, M., & Hayes, G. R. (2015). Evaluating a Collaborative iPad Game's Impact on Social Relationships for Children with Autism Spectrum Disorder. *ACM Transaction on Accessible Computing*, 7(1), 3:1-3:18. <https://doi.org/10.1145/2751564>

This research project studies how the practice of collaborative games on iPad in children with ASD can develop social relationships. To do so, the authors propose an experimental protocol of ABAB type, interchanging sessions of collaborative mini-games on iPad and sessions of Lego games. Based on a qualitative evaluation with eight participants, the authors provide design recommendations to foster the development of social relationships through collaborative games.

* Brox, E., Luque, L. F., Evertsen, G. J., & Hernandez, J. E. G. (2011). Exergames for elderly: Social exergames to persuade seniors to increase physical activity. In 2011 5th *International Conference on Pervasive Computing Technologies for Healthcare* (PervasiveHealth) (p. 546-549).

Magazine article on the interests of exergams to motivate seniors to be physically active.

* Buisine, S., Besacier, G., Aoussat, A., & Vernier, F. (2012). How do interactive tabletop systems influence collaboration? *Computers in Human Behavior*, 28(1), 49-59. <https://doi.org/10.1016/j.chb.2011.08.010>

Evaluation of the impact of a collaborative table during a creative problem solving process on collaboration and group work.

* Chen, X., Siebourg-Polster, J., Wolf, D., Czech, C., Bonati, U., Fischer, D., ... Strahm, M. (2017). Feasibility of Using Microsoft Kinect to Assess Upper Limb Movement in Type III Spinal Muscular Atrophy Patients. *PLoS ONE*, 12(1). <https://doi.org/10.1371/journal.pone.0170472>

Design of a Kinect application used in therapeutic contexts for the early diagnosis of spinal muscular atrophy.

* Davis, J. W., & Bobick, A. F. (1998). Virtual PAT: A Virtual Personal Aerobics Trainer. In *Workshop on Perceptual User Interfaces* (p. 13-18).

Virtual PAT was one of the first systems with video-based motion capture allowing personalized feedback on performance.

* Dietz, P., & Leigh, D. (2001). DiamondTouch: A Multi-user Touch Technology. In Proceedings of the 14th Annual *ACM Symposium on User Interface Software and Technology* (p. 219-226). New York, NY, USA: ACM. <https://doi.org/10.1145/502348.502389>

This article presents the DiamondTouch interactive table. This technology has the ability to identify each user independently (i.e., identify the user for each finger touching the surface).

* Edwards, J., Jeffrey, S., May, T., Rinehart, N. J., & Barnett, L. M. (2017). Does playing a sports active video game improve object control skills of children with autism spectrum disorder? *Journal of Sport and Health Science*, 6(1), 17-24. <https://doi.org/10.1016/j.jshs.2016.09.004>

The authors present the evaluation of Kinect based commercial exergams in terms of developments in gross motor skills in children with ASD. This experimental approach shows that gross motor skills do not improve after the intervention (6 sessions of 45 minutes each) but that perceived motor competence does. This study shows the importance of movement and task choice for improving motor skills.

* Farr, W., Yuill, N., & Hinske, S. (2012). An augmented toy and social interaction in children with autism. *International Journal of Arts and Technology*, 5(2-4), 104-125. https://doi.org/10.1504/IJART.2012.046270

In this paper it is a real and therefore tangible game (a knight's castle) that is augmented. When certain elements of the game are positioned nearby, sounds are triggered. The authors study more particularly the impact of the "configurability" of the device on the engagement and socialization of children playing at the same time. A qualitative and quantitative evaluation with 12 children with ASD shows the increase in social behaviors in the case of configurable play.

* Farr, W., Yuill, N., & Raffle, H. (2010). Social benefits of a tangible user interface for children with Autistic Spectrum Conditions. *Autism*, 14(3), 237-252. <https://doi.org/10.1177/1362361310363280>

The authors study the benefits of using "augmented" games (also called Tangible User Interface, or TUI) in the support of autistic people. In a first study, Farr et al. (2010) evaluate the use of a TUI called Topobo, a construction game with programmable kinetic memory. The dual interest of this game is that it is on the one hand programmable, which encourages the child's engagement, and on the other hand dynamic, dynamic constructed creatures attract attention and provide opportunities for social interaction.

* Fernaeus, Y., Tholander, J., & Jonsson, M. (2008). Towards a New Set of Ideals: Consequences of the Practice Turn in Tangible Interaction. In Proceedings of the 2nd *International Conference on Tangible and Embedded Interaction* (p. 223-230). New York, NY, USA: ACM. <https://doi.org/10.1145/1347390.1347441>

Presentation by the authors of the recent evolution of practices within the tangible interaction research stream.

* Fitzmaurice, G. W., Ishii, H., & Buxton, W. A. S. (1995). Bricks: Laying the Foundations for Graspable User Interfaces. In Proceedings of the SIGCHI *Conference on Human Factors in Computing Systems* (p. 442-449). New York, NY, USA: ACM Press/Addison-Wesley Publishing Co. <https://doi.org/10.1145/223904.223964>

The authors introduce in this paper and for the first time the notion of catchable user interface.

* Gal, E., Bauminger, N., Goren-Bar, D., Pianesi, F., Stock, O., Zancanaro, M., & (Tamar) Weiss, P. L. (2009). Enhancing social communication of children with high-functioning autism through a co-located interface. *AI & SOCIETY, 24*(1), 75. <https://doi.org/10.1007/s00146-009-0199-0>

The authors develop the StoryTable, where dyads of children with ASD are involved in collaborative storytelling. The children must choose together the story elements such as character and background. Some actions can only be done by one child while others must be done jointly, for example, selecting the background (i.e., the button must be touched by two).

* Giusti, L., Zancanaro, M., Gal, E., & Weiss, P. L. (Tamar). (2011). Dimensions of Collaboration on a Tabletop Interface for Children with Autism Spectrum Disorder. In Proceedings of the SIGCHI *Conference on Human Factors in Computing Systems* (p. 3295-3304). New York, NY, USA: ACM. <https://doi.org/10.1145/1978942.1979431>

The authors design a series of mini-games to develop three dimensions of collaboration in children with ASD: joint action, resource sharing, and mutual planning. For joint action, the two children must move a basket together under trees to catch falling apples. Another version of the game implements different roles for each child: one child touches stars to make them fall while the other moves the basket to receive them. Finally, for the last game, the dyad has to rebuild a bridge but each child has access to only part of the necessary parts. The authors emphasize the importance of considering the practitioner's role in the interaction involving two children with ASDs: a system of validation by touch by the practitioner allows the practitioner to maintain control over the course of the dyadic activity (e.g., by tempering the actions of an impulsive child).

* Grynszpan, O., Martin, J.-C., & Nadel, J. (2008). Multimedia interfaces for users with high functioning autism: An empirical investigation. *International Journal of Human-Computer Studies*, 66(8), 628-639. <https://doi.org/10.1016/j.ijhcs.2008.04.001>

This article describes the design of a multimedia system for training skills related to understanding the emotions expressed by characters. Training was conducted with 10 adolescents with ASD and 10 neurotypical adolescents for 13 weeks. A rich interface (displaying combinations of facial expression images, text dialogues, and text-to-speech) was compared to a simple interface (text dialogues only). Adolescents with ASD performed better after training than before training when evaluated with the simple interface (and not the rich multimedia interface). Neurotypical adolescents performed better after training than before training regardless of which version of the interface they were tested with after training.

* Hornecker, E., & Buur, J. (2006). Getting a Grip on Tangible Interaction: A Framework on Physical Space and Social Interaction. In Proceedings of the SIGCHI *Conference on Human Factors in Computing Systems* (p. 437-446). New York, NY, USA: ACM. <https://doi.org/10.1145/1124772.1124838>

The article introduces the notion of tangible interaction in the field of human-machine interaction.

* Hsiao, H.-S., & Chen, J.-C. (2016). Using a gesture interactive game-based learning approach to improve preschool children's learning performance and motor skills. *Computers & Education, 95*, 151-162. <https://doi.org/10.1016/j.compedu.2016.01.005>

This article presents a game where the child takes the role of a soccer goalkeeper: thanks to the capture of his movements, the system displays his hands in a soccer cage with the task of catching the balls pulled by a virtual character. The objective of the exercise is to train motor skills.

* Jordà, S., Geiger, G., Alonso, M., & Kaltenbrunner, M. (2007). The reacTable: Exploring the Synergy Beetween Live Music Performance and Tabletop Tangible Interfaces. In Proceedings of the 1st *International Conference on Tangible and Embedded Interaction* (p. 139-146). New York, NY, USA: ACM. <https://doi.org/10.1145/1226969.1226998>

Presentation of the interactive and tangible Reactable table made for the composition of musical performances.

* Kourakli, M., Altanis, I., Retalis, S., Boloudakis, M., Zbainos, D., & Antonopoulou, K. (2017). Towards the improvement of the cognitive, motoric and academic skills of students with special educational needs using Kinect learning games. *International Journal of Child-Computer Interaction*, 11, 28-39. <https://doi.org/10.1016/j.ijcci.2016.10.009>

Evaluation of the contribution of the Kinems Suite practice on motor, cognitive and academic skills.

* Lamboglia, C. M. G. F., Silva, V. T. B. L. da, Vasconcelos Filho, J., De, E., Pinheiro, M. H. N. P. , Munguba, M. C. da S, Silva Junior, F. V. I., de Paula, F. A. R., da Silva, C. A. B. (2013). Exergaming as a Strategic Tool in the Fight against Childhood Obesity: A Systematic Review. *Journal of Obesity*, 2013, e438364. <https://doi.org/10.1155/2013/438364>

Magazine article on the use of exergams to fight obesity in children.

* Legoff, D. B., & Sherman, M. (2006). Long-term outcome of social skills intervention based on interactive LEGO© play. *Autism*, 10(4), 317-329. <https://doi.org/10.1177/1362361306064403>

The authors present an evaluation of therapy for children with autism based on group practice of LEGO play. One of the key points of the therapy is to assign clear roles to the children.

* Lyons, E. J., Tate, D. F., Komoski, S. E., Carr, P. M., & Ward, D. S. (2012). Novel Approaches to Obesity Prevention: Effects of Game Enjoyment and Game Type on Energy Expenditure in Active Video Games. *Journal of Diabetes Science and Technology*, 6(4), 839-848. <https://doi.org/10.1177/193229681200600415>

This research evaluates the impact of 2 hours of practice of Wii Fit games on the pleasure and energy expended by adults.

* Martin, J.-C. (2018). Virtual agents for learning social skills in autisme : a review. *Childhood,* (1), 13-30.

Journal article on the development and evaluation of virtual agents for learning social skills in autism.

* Pares, N., Masri, P., Wolferen, G. van, & Creed, C. (2005). Achieving dialogue with children with severe autism in an adaptive multisensory interaction: the " MEDIATE " project. *IEEE Transactions on Visualization and Computer Graphics*, 11(6), 734-743. <https://doi.org/10.1109/TVCG.2005.88>

The MEDIATE project is one of the first research projects proposing an immersive and multisensory environment aimed at developing the sense of control ("agency") as well as the sense of creative expression in children with ASD. Based on pressure sensors on the ground under a carpet and on speech recognition, this device, which uses the EyesWeb platform, is equipped with two giant screens and a tactile printing area. The system adapts in real time to the actions of the child while avoiding repetitive behaviors.

* Piper, A. M., O'Brien, E., Morris, M. R., & Winograd, T. (2006). SIDES: A Cooperative Tabletop Computer Game for Social Skills Development. In Proceedings of the 2006 20th Anniversary *Conference on Computer Supported Cooperative Work* (p. 1-10). New York, NY, USA: ACM. <https://doi.org/10.1145/1180875.1180877>

The SIDES project uses the DiamondTouch table to develop a cooperative game for four players where children must build a path for a frog on water lilies together. The activity mobilizes the skills of negotiation, taking turns, active listening and taking perspective. The interaction is structured in turns, with each child having his or her turn and buttons that only he or she can activate (which prevents another child from finishing another child's action). He decides by himself when to pass his turn via a specific button.

* Raffle, H. S., Parkes, A. J., & Ishii, H. (2004). Topobo: A Constructive Assembly System with Kinetic Memory. In Proceedings of the SIGCHI *Conference on Human Factors in Computing Systems* (p. 647-654). New York, NY, USA: ACM. <https://doi.org/10.1145/985692.985774>

Presentation of the Topobo programmable kinetic memory building set.

* Ringland, K. E., Zalapa, R., Neal, M., Escobedo, L., Tentori, M., & Hayes, G. R. (2014). SensoryPaint: A Multimodal Sensory Intervention for Children with Neurodevelopmental Disorders. In Proceedings of the 2014 ACM *International Joint Conference on Pervasive and Ubiquitous Computing* (p. 873-884). New York, NY, USA: ACM. <https://doi.org/10.1145/2632048.2632065>

This paper presents the design and evaluation of "SensoryPaint", an interactive device based on body movements that can be used in sensory integration therapies. The child sees on a screen his silhouette, whose color varies according to distance, and can grasp balls detected by the system that become virtual paintbrushes. Two qualitative evaluations are presented, underlining the importance of the appropriation of the device by the practitioners.

* Silva, G. F. M., Raposo, A., & Suplino, M. (2015). Exploring Collaboration Patterns in a Multitouch Game to Encourage Social Interaction and Collaboration among Users with Autism Spectrum Disorder. *Computer Supported Cooperative Work* (CSCW), 24(2-3), 149-175. <https://doi.org/10.1007/s10606-014-9214-1>

The authors introduce the notion of "Collaboration Patterns" as different levels of complexity that can characterize an interaction rule in a multi-user game. The 4 levels are implemented in an interactive tabletop game. An evaluation with 5 children with ASD playing as peers (for a total of 51 sessions) indicates that the applied sequence of patterns encourages collaborative activities.

* Staiano, A. E., Abraham, A. A., & Calvert, S. L. (2012). Motivating Effects of Cooperative Exergame Play for Overweight and Obese Adolescents. *Journal of Diabetes Science and Technology*, 6(4), 812-819. <https://doi.org/10.1177/193229681200600412>

Study on the motivational effect of playing cooperative Wii games.

* Staiano, A. E., & Calvert, S. L. (2011). Exergames for Physical Education Courses: Physical, Social, and Cognitive Benefits. *Child development perspectives*, 5(2), 93-98. <https://doi.org/10.1111/j.1750-8606.2011.00162.x>

Journal article on the benefits of integrating exergams into physical education classes.

* Tartaro, A., Cassell, J., Ratz, C., Lira, J., & Nanclares-Nogués, V. (2014). Accessing Peer Social Interaction: Using Authorable Virtual Peer Technology as a Component of a Group Social Skills Intervention Program. *ACM Transactions on Accessible Computing*, 6(1), 2:1-2:29. <https://doi.org/10.1145/2700434>

This article describes a system with a virtual character in which the child with ASD can 1) interact with a virtual child, 2) create social behaviours for the virtual child, 3) control the virtual child's responses when interacting with a third party. The authors describe an evaluation with 8 children during lessons on social skills (getting to know someone, taking turns, how and when to interrupt, ...) for 11 weeks. The results suggest an improvement in some social skills.

* Velloso, E., Bulling, A., & Gellersen, H. (2013). MotionMA: Motion Modelling and Analysis by Demonstration. In Proceedings of the SIGCHI *Conference on Human Factors in Computing Systems* (p. 1309-1318). New York, NY, USA: ACM. <https://doi.org/10.1145/2470654.2466171>

MotionMA is an interactive software that allows pre-recorded movement practice training by providing real-time feedback on the movement to be performed via the display of arrows indicating the position change to be made.

* Villafuerte, L., Markova, M., & Jorda, S. (2012). Acquisition of Social Abilities through Musical Tangible User Interface: Children with Autism Spectrum Condition and the Reactable. In *CHI '12 Extended Abstracts on Human Factors in Computing Systems* (p. 745-760). New York, NY, USA: ACM. <https://doi.org/10.1145/2212776.2212847>

This paper presents an application of the Reactable interactive musical table for social skills training of children with ASD.

* Wade, J., Sarkar, A., Swanson, A., Weitlauf, A., Warren, Z., & Sarkar, N. (2017). Process Measures of Dyadic Collaborative Interaction for Social Skills Intervention in Individuals with Autism Spectrum Disorders. *ACM Transactions on Accessible Computing*, 10(4), 13:1-13:19. <https://doi.org/10.1145/3107925>

The authors present a collaborative pong game for children with ASD called DOSE (Dyad-Operated Social Encouragement). The game has four different modes: a "single" mode to practice, a "dyad against artificial intelligence" mode where the two children share the keyboard to steer the bar (paradigm of forced collaboration), a "rally" mode where the two children each have a bar and must make as many passes as possible, and finally a "competition" mode.

* Zhang, L., Fu, Q., Swanson, A., Weitlauf, A., Warren, Z., & Sarkar, N. (2018). Design and Evaluation of a Collaborative Virtual Environment (CoMove) for Autism Spectrum Disorder Intervention. *ACM Transactions on Accessible Computing*, 11(2), 11:1-11:22. <https://doi.org/10.1145/3209687>

Presentation of the CoMove application in which a dyad of children with ASD must perform a tangram. Three modes are implemented: turn-based game where each child takes turns to do an action, information sharing game where one of the children does not have the colors of the pieces and therefore has to exchange with his partner, and collaborative game where the children have to move the pieces simultaneously. Quantitative data recording is carried out in order to facilitate evaluation of progress by practitioners.

1. [↑](#footnote-ref-1)
2. Complete information on this international convention can be found at <http://www.firah.org/centre-ressources/>in the "understand to act" tab. This convention is a binding text for countries that have ratified it, just like the convention on children's rights for example. [↑](#footnote-ref-2)