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Abstract A growing number of studies investigate robot intervention in the case of Autism. Most of these studies are either focused on social skills or robot design. However, a large number of autistic children also suffer from motor deficits which are directly correlated with impaired communication skills and severity of autism. While several robot-centered reviews or reviews interested in social robotics for autism have already been made, a review on robot-based motor rehabilitation in autism was still lacking. In this paper, we dedicate our review to motor rehabilitation in autism, notably using robots. To do so, we searched the PubMed, IEEE, PsycNet and Science Direct databases. We show that although this research is promising, it has been neglected and would benefit from more consideration. The goal of this review is to highlight the relevance of past work and insist on the dire need to develop this research.

Keywords autism · motor coordination · therapeutic robotics · motor rehabilitation

1 Introduction

The first description of Autism Spectrum Disorder (ASD) was realized by Kanner in 1943. ASD is an umbrella term with different manifestations of autism at various levels of severity (formerly Kanner's autism, Asperger syndrome, high functioning autism).

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As of 2018, the prevalence of ASD is estimated at 1.7 % of the population (2.7 % of boys and 0.67 % of girls). Diagnosis of ASD has been increasing for decades, but there is no consensus whether this is the result of increased awareness, improved detection, expanding definitions, increase in incidence or a combination of all these factors. Diagnosis now relies on the DSM-V (Fifth Edition of the Diagnosis and Statistical Manual of Mental Disorders, 2013). It highlights two areas of impairment: social communication and behavioral domain which can be rated by level of severity. ASD is usually associated with a wide range of comorbidities such as developmental coordination disorder (DCD), attention deficit hyperactivity disorder (ADHD), obsessive compulsive disorder (OCD), gastrointestinal symptoms...

ASD cannot be "cured" but abilities can be enhanced thanks to different types of therapy. Early intervention is thus paramount. Several robot-centered reviews have studied adequacy of robot design and robot abilities. The goal of those reviews is to determine the required components for an interaction which would elicit engagement in ASD children. This is not our goal, this review is focused on motor rehabilitation for ASD and particularly using robots. For a robot-centered review, see Huijnen et al. (2016); Cabibihan et al. (2013).

Though a myriad of studies on motor rehabilitation for stroke, Parkinson or Cerebral Palsy exist, these studies have rarely been extended to Autism Spectrum Disorders (ASD). Moreover, most of the child - robot interaction studies present important methodological limitations. Some have no therapeutic goal, but only observe what happens. Even when the study has a clearly identified goal, few have a control group and realize follow-up tests to evaluate the actual effectiveness. So for this review, we attempted to impose some exclusion criteria for the articles to be included: they had to have a control group of non-ASD children and more than two children in each group. Since we focus on therapy-oriented papers, an identified therapeutic goal, a pre-evaluation and a post-evaluation of motor skills were required. However, since only few papers fit the criteria, we had to be less demanding.

In this work, the PubMed, IEEE, PsycNet and Science Direct databases were searched with the following combinations of keywords: ({autism | ASD} & {motor | movement} & {rehabilitation | therapy | intervention} & "robot") | ({autism | ASD} & {imitation | coordination | tactile | touch | haptic}). The goal of this review is to highlight the relevance of past work and insist on the dire need to develop this research. We show that although this research is promising, it has been neglected and would benefit from more consideration and from a rigorous methodological approach.

The paper is organized as follows: in the second part of this paper, we present motor impairments in ASD, then in the third part, we talk about the different types of robot-therapy for motor rehabilitation in ASD. Finally, we discuss and conclude this paper.

2 Motor Impairments in ASD

Impaired motor functioning has been consistently observed by parents and clinicians (see Peña de Moraes et al. (2017) for a review of impaired motor learning in ASD). It involves mostly general clumsiness in gait (Biffi et al., 2018; Dufek et al., 2017; Rinehart et al., 2006a,b; Vernazza-Martin et al., 2005), balance (Molloy et al., 2003), manual dexterity (Kushki et al., 2011; Alaniz et al., 2015), praxis (Abu-Dahab et al., 2013; Rodgers et al., 2019; Sacrey et al., 2014; Glazebrook et al., 2006; Nazarali et al., 2009) and coordination (Curioni et al., 2017; Xavier et al., 2018; David et al., 2009; Romero et al., 2016).

Studies also reported that severity of motor skill impairments was directly correlated with severity of social and communication impairments (MacDonald et al., 2014; Dziuk et al., 2007; Manwaring et al., 2017; Dadgar et al., 2017; Higashionna et al., 2017; Jasmin et al., 2009; Purpura et al., 2016; Hilton et al., 2012; Goldman et al., 2009) since motor skills are a paramount part of social communication and can impact the understanding of others' actions (Gallese et al., 2013). Cummins et al. (2005) showed that autistic children with motor deficits had less empathy and greater social difficulties.

34 to 79 % of the autistic population (opposed to 5% of the typical population) is affected by Developmental Coordination Disorders (DCD) (Kopp et al., 2010). This involves nervous tics, laterality disorders, tip-toeing, synkinesis, catatony, oculomotor disorders, diadochokinesis, dysgraphy, inappropriate manual force, low digital speed and slowness of dexterity. Overall 80% - 90% of children with ASD show some degree of motor abnormality (David et al., 2009; Dziuk et al., 2007; Ghaziuddin and Butler, 1998; Hilton et al., 2012; Ming et al., 2007; Provost et al., 2007).

Motor control is classically divided into motor planning in the higher levels and execution in the lower levels. Besides, movement execution involves connections between multiple brain regions. First, the prefrontal cortex communicates with the basal ganglia and decides the motor strategy based on sensory information (auditory, visual, somatic, proprioceptive). Then the primary motor cortex, supplementary motor area and the cerebellum compute the muscle activation sequence to perform the task. It is believed that the angular and supramarginal gyri are the site of storage of learned time-space movement representations which help to program the premotor cortex. Finally, the premotor cortex is involved in translating movement representations into motor programs, which then activates the motor cortex for execution. The motoneurons and spinal interneurons generate the movement and adjust it, if needed.

A crucial step in motor learning is the ability to form internal models (Krakauer and Shadmehr, 2007), i.e. predict the consequences of motor commands and learn from errors to adapt. The cerebellum is a site for acquisition of internal models and it has been observed in post-mortem exams that the cerebellum is indeed abnormal in individuals with ASD (Williams et al., 1980; Ritvo et al., 1986; Bauman and Kemper, 2005; Bailey et al., 1998; Fatemi et al., 2002). However, Larson et al. (2008) showed that ASD children had no problem acquiring new internal models, thus hypothesizing that the dysfunction stems from another region (basal ganglia, frontal or parietal) or from connectivity abnormalities between regions (Balsters et al., 2018). Indeed, low activation of the cerebellum and motor execution networks also occurs in motor coordination tasks (Mostofsky et al., 2009). Autism is characterized by hypo-functioning of the connections in the higher level of the brain (connection between the frontal lobe and the rest of the cortex) and hyper-functioning at the lower level. It has thus been hypothesized that the decreasing cerebellum activity could evidence a difficulty to transmit motor execution from the cortical regions to the areas associated with "automated" motor execution (Stoit et al., 2013; Oldehinkel et al., 2018; Schipul et al., 2011). Over-connectivity between the thalamus and cortical sensory processing areas (Traynor et al., 2018; Mizuno et al., 2006), as well as between basal ganglia and somatosensory and motor cortices has also been reported (Traynor et al., 2018; Di Martino et al., 2011; Turner et al., 2006; Cerliani et al., 2015). MRI studies have shown microstructural compromise in motor, sensory and cerebellar pathways (Nair et al., 2013; Carper et al., 2015; Sivaswamy et al., 2010; Hanaie et al., 2013; Nair et al., 2015). Recently, altered white matter has been discovered in the left somatosensory area and its descending pathways connecting to the cerebellum (Lin et al., 2019).

Besides, fMRI studies have reported reduced volume in the fastigial nuclei and cerebellar vermis lobules VI-VII. This region is responsible for ocular motor function, verbal working memory and speech coordination.

However, in ASD, implicit motor learning ability remains intact (Nemeth et al., 2010; Izadi-Najafabadi et al., 2015; Gordon and Stark, 2007). Implicit motor learning is defined as the acquisition of motor skills without conscious access to what was learned or even to the fact that learning occurred. Explicit motor learning occurs when the goal and the execution are plainly explained to the children. So children can exhibit a clumsy gait when consciously walking and walking becomes smooth when they focus on another task.

Moreover, imitation is an essential part of child development. It can be defined as the replication with retention of certain characteristics of an observed motor act by an individual. Imitation follows the observed act. While contributing to social learning, it also plays a critical role in the development of Theory of Mind, social cognition and communication skills. A popular belief is that ASD individuals lack Theory of Mind. Theory of Mind is the ability to attribute mental states to oneself and to others as well as understand that others have different mental states from one's own. It also involves inferring that those states can cause action (Baron-Cohen et al., 2001; Heyes, 2001). Jones et al. (2018) showed that there is an association between lack of Theory of Mind and restricted repetitive behaviors (motor stereotypies).

In the case of ASD, there is a controversy concerning imitation deficits (Xavier et al., 2015; Rogers et al., 2010b; Vivanti et al., 2011; Salowitz et al., 2013; Vanvuchelen et al., 2011; Vivanti et al., 2014; Sowden et al., 2016) and the broken mirror theory which postulates that a deficient motor neuron system (MNS) contributes to imitation deficits (Southgate and Hamilton, 2008). The MNS encompasses regions in the inferior frontal gyrus and the inferior parietal lobule. It is involved in both the movement production and action observation (Rizzolatti and Craighero, 2004; Guillot et al., 2009). While some researchers reported autism-specific impairments in imitation (Meltzoff, 1993; Rogers and Pennington, 1991) and a dysfunctional MNS (Iacoboni et al., 2005; Oberman and Ramachandran, 2007), others showed intact ability to engage in imitation (Hammes and Langdell, 1981; Press et al., 2010; Bird et al., 2007), preserved action representation and thus a functional MNS (Chen et al., 2018; Carmo et al., 2013; Hamilton et al., 2007). However, neuroimaging studies evidenced that neural activity and connectivity in regions for imitation may be abnormal in ASD (Bernier et al., 2007; Dapretto et al., 2006). Nishitani et al. (2004) examined oral-facial imitation in TD (Typical Development) and ASD using magnetoencephalography (MEG). They observed neural activity that temporally progressed from the primary visual cortex (V1) to the superior temporal sulcus (STS) to the inferior parietal lobule (IPL) to the inferior frontal gyrus (IFG) and finally to the primary motor cortex. Similar activation was observed in both TD and ASD participants, but activation was weaker and delayed in IFG for the ASD group. Villalobos et al. (2005) also found decreased functional connectivity between V1 and IFG bilaterally in a fMRI study where they investigated interregional synchronization with visual areas.

Vanvuchelen et al. (2011) postulated that imitation deficits can be explained by either an impairment in the selection mechanism due to a poor preferential attention to biological motion and in recognizing intentional actions or by an impaired correspondence mechanism due to a poor viewpoint transformation and visuomotor mapping.

Furthermore, some individuals with ASD are hyposensitive. Their touch can be inappropriate since they do not have correct sensory feedback and they can unwillingly hurt other persons (Foss-Feig et al., 2012). On the other hand, others present hypersensitivity and can be overwhelmed by touch (Blakemore et al., 2006; Riquelme et al., 2016). Tactile interaction could be a useful communication tool to complete inadequate verbal skills. Caldwell (1996) even suggests that touch can replace defective means of communication.

Studies have also endeavoured to make robots "autistic" by reproducing the motor deficits observed in order to better design motor rehabilitation studies. Idei et al. (2018) investigated the effects of increased and decreased sensory precision on adaptive motor behaviors. They showed that aberrant precision leads to behavioral rigidity. Barakova and Chonnaparamutt (2009) studied the temporal aspect of sensory precision with a mobile robot. They predicted that grasping is performed properly by ASD children except in the presence of proximal obstacles.

3 Method

3.1 Search Procedure

For this review, we searched the PubMed, IEEE, PsycNet and Science Direct databases with the following combinations of keywords: ({autism | ASD} & {motor | movement} & {rehabilitation | therapy | intervention} & "robot") | ({autism | ASD} & {imitation | coordination | tactile | touch | haptic}). This search yielded 2550 results. After removal of duplicates and irrelevant results, we selected 53 papers. When several papers referred to the same study, we selected the paper which detailed the experimental protocol and results more accurately. For each paper, we read the abstract and possibly looked into the paper for additional information. If the paper fit our criteria, it was studied more thoroughly and its bibliography was searched for additional references. Eight papers were selected by browsing through the references.

3.2 Inclusion Criteria

We attempted to impose some rigorous exclusion criteria for the articles to be included: they had to have a control group of ASD children and more than two children in each group. Since we focus on therapy-oriented papers, an identified therapeutic goal, a pre-evaluation and a post-evaluation of motor skills were required. However, since only three papers fit the criteria, we had to be less demanding. Thus our final inclusion criteria are as follows: more than two ASD children, an identified therapeutic goal to improve motor skills and some form of objective evaluation. So after applying the criteria, twelve papers remained.

3.3 Data Extraction

The studies identified in the preliminary search were first assessed for inclusion by extracting relevant information (number of participants, use of a control group, therapeutic goal). Selected studies were then summarized in terms of participants' characteristics, assessment of motor skills before, during and after the study, duration and frequency of the intervention, therapeutic goal, robot used, tasks performed during the intervention, significance of the outcome of the intervention. The studies were classified according to their primary goal: improve coordination, imitation, fine motor skills, sensorimotor skills.

4 Robot-based Motor Rehabilitation in Autism

Motor skills can be tackled from different points of view as they encompass a wide range of skills: fine motor skills, gross motor skills, motor coordination, motor imitation, sensorimotor skills. Research studies usually focus on one specific skill. See Table 1 for an overview.

4.1 Coordination

Moorthy and Pugazhenthi (2016) used a custom-made LEGO snatcher robot to enhance psychomotor skills in ASD children. They had 20-30 minutes weekly sessions for an undetermined period. Five ASD children participated in the study and imitated the robot in four different activities which basically consisted in turning and picking up a basket. This imitation task was meant to improve non verbal imitation, hand-eye coordination, balanced body movements and backward walking. The children' progress was assessed thanks to success rate and therapists' testimony. It was reported that the children had been able to generalize the concept of pick and place and had improved eye-hand coordination.

So et al. (2018) used the Nao robot to tell social stories while gesturing. Fifteen ASD children participated in the intervention condition in four 30-minutes sessions. They were instructed to imitate the robot gestures (fourteen intransitive gestures). They had control groups of fifteen ASD children and fifteen TD children. Results showed improvement of accurate or appropriate intransitive gestures for the intervention group and also that gestural production accuracy became similar to the TD group. The intervention group also produced more verbal markers while gesturing. Moreover, they found that gestural recognition skills were correlated to the learning ability of gestural production accuracy. Before the study, language and communication abilities and motor skills were assessed by the Psychoeducational Profile, Third Edition (Schopler, 2005) and the BOT2 test. Delayed BOT2 post-test showed that progress was maintained.

Srinivasan et al. (2015) compared rhythm and robot intervention (Nao and Rovio) with thirty-six ASD children. The children were divided into three groups: robot, rhythm intervention and control group. Each group engaged in joint action-based gross motor and/or fine motor activities that promoted social skills (eye contact, turn taking, greeting and imitation) as well as communication skills. The rhythm and robot groups promoted balance, coordination, interpersonal synchrony, imitation and manual dexterity. The control group focused on fine motor skills. Training lasted eight weeks and four sessions were provided each week. Motor skill deficits were assessed with the MABC-2 test (Movement Assessment Battery for Children Henderson and Sugden (1992)) and evolution was followed with the BOTMP-2 (Bruininks-Oseretsky Test of Motor Proficiency (Bruninks, 1978)). They observed more negative behaviours in the robot and rhythm groups but the frequency decreased over the weeks for the rhythm group. Negative behaviours can be explained by the fact that the activities in those groups were highly unconstrained, which generated a lot of stress for the children. However, there was no improvement for the robot group. The authors attributed this to poor robot performance.

According to this paper, rhythm therapy should be favoured as long as robots are so technically restricted, especially on the movement generation side. Indeed, in long-term interventions, children tend to grow bored of such limited robots.

4.2 Imitation

Robots have been extensively used in ASD children-robot interactions to observe imitation abilities (Boucenna et al., 2014; Bugnariu et al., 2013; Conti et al., 2015). While Pierno et al. (2008) observed that seeing a robot movement elicits a faster movement to grasp a ball than seeing a human movement in ASD children, Bird et al. (2007) showed that ASD adults imitate the hand of a robot more often than the hand of a human.

Greczek et al. (2014) studied the influence of graded cueing feedback to improve imitation with twelve ASD children during five sessions over the course of 2.5 weeks. Six children received maximum feedback while the others received adaptive feedback depending on their performance. They computed imitation accuracy using a Kinect sensor and showed that graded cueing lead to non-decreasing trend in imitation accuracy compared to the non-adaptive condition. Moreover, Zheng et al. (2016) also used the Nao robot with eight ASD and eight TD children. They were asked to imitate a robot or a human raising one hand, raising two hands, waving and reaching arms out to the side. They evaluated accuracy of imitation using a Kinect. They observed more engagement when the child interacted with the robot and better imitation improvement in the robot session for the ASD children than in the human condition. The typical children, however, showed no significant improvement. Ali et al. (2019) designed a study to improve joint attention and imitation, which they tested with twelve ASD children across eight sessions over six months. The children observed two robots imitating each other and then had to imitate one of the robots performing arm gestures. Success rate from the Kinect and EEG data were assessed. The paper focuses mainly on joint attention, for which it shows improvement, there was however no improvement in imitation skills. Beer et al. (2016) combined music therapy with the Nao robot to improve imitation with four ASD children over the course of six weeks. The robot was integrated to the regular music therapy sessions of the children. The robot performed dance moves in accordance with the therapy music. They observed an increase in frequency of imitating the robot dance and a decrease in therapist's prompts.

4.3 Fine Motor Skills

Srinivasan et al. (2015) used the robot Nao and the mobile robot Rovio in a motor rehabilitation study. They had thirty-six ASD children divided into three groups: control, rhythmic and robot groups. The control group did table top activities to develop fine motor skills. The rhythm group performed whole-body discrete imitation and interpersonal synchrony-based rhythmic games with music. The robot group performed dual and multilimb imitation and synchrony-based games. The aim for the latter groups was to improve balance, bilateral coordination, imitation, interpersonal synchrony and manual dexterity.

So et al. (2019) endeavoured to improve fine motor skills in a study where a robot or a human (control group) engaged in daily life conversations and demonstrated fourteen intransitive gestures to twenty-three ASD children. The intervention lasted nine weeks. It started with a pre-test (BOTMP2) and post-tests were performed immediately after the training and two weeks after to assess the generalization effect. Results showed that the robot acting as a teacher was as effective as the human. However, children in the robot group were more likely to engage eye-contact with the teachers. Gestural production improved for both groups.

Palsbo and Hood-Szivek (2012) used a haptic robot

	Reference	Robot used	Number of ASD Subjects (age)	Control Group	Task	Therapeutic Goal	Efficiency Evaluation
Imitation	Ali et al. (2019)	Nao	12 (7.96 ± 2.36)	0	Imitate the robot performing arm movements	Improve joint attention and imitation	EEG and Kinect
	Beer et al. (2016)	Nao	4 (11 ± 3.56)	0	Children imitate the robot performing dance moves	Improve imitation	Analysis of video data
	Greczek et al. (2014)	Nao	12 (7-12)	0	Imitate the robot. The robot gives feedback to the child and corrects the child	improve imitation	imitation accuracy
	Zheng et al. (2016)	Nao	8 (3.83 ± 0.54)	8 (3.61 ± 0.64)	Imitate robot or experimenter raising one hand, raising two hands, waving, and reaching arms out to the side	improve imitation	imitation accuracy
Coordination	Moorthy and Pugazhenthi (2016)	LEGO snatcher robot	5 (4 - 10)	0	Children imitate the robot in 4 activities	Improve non verbal imitation, hand-eye coordination and balanced body movements and backward walking	Evolution of success rate
	So et al. (2018)	Nao	15 (4 - 6)	15 ASD and 15 TD children	Nao narrates five stories and gestures. ASD children were told to imitate the gestures	improve motor skills	PEP-3 and BOTMP2
	Srinivasan et al. (2015)	Nao & Rovio	12 (7.6 ± 2.2)	12 doing table top activities & 12 undergoing rhythm therapy	Rhythm group: whole-body discrete imitation and interpersonal synchrony-based rhythmic games with music; robot group: dual and multilimb imitation and synchrony-based games	Improve balance, bilateral coordination, imitation, interpersonal synchrony, and manual dexterity	MABC-2 & BOTMP2

Table 1 Summary table on imitation rehabilitation using robots. (BEERY-VMI: Beery-Buktenica Developmental Test of Visual-Motor Integration; PEP: Psychoeducational Profile; MABC: Movement Assessment Battery for Children; CARS: Childhood Autism Rating Scales)

	Reference	Robot used	Number of ASD Subjects (age)	Control Group	Task	Therapeutic Goal	Efficiency Evaluation
Fine Motor Skills	Moorthy et al. (2016)	Snatcher robot	8 (?)	0	recognize left/right robotic shoe and close velcro	enhance the psychomotor skills like pincer grasp, hand-eye coordination and bilateral coordination	pre-test & post-test
	Palsbo and Hood-Szivek (2012)	Haptic robot	18 children with impairments (5 with ASD)	0	Different writing tasks	Improve fine motor skills	BEERY-VMI test
	So et al. (2019)	Nao	12 (9.17 ± 1.29)	11 ASD children interacting with a human	Robot or Human engaged in daily life conversations and demonstrated 14 intransitive gestures	improve fine motor skills	BOTMP2
Touch	Costa et al. (2015)	Kaspar	8 (4-15)	0	perform different activities with the robot (based on identification of body parts and imitation)	improve touch, awareness of body parts	pre-test & post-test
	Robins and Dautenhahn (2014)	Kaspar	24 (6-9)	0	perform a tactile game with the robot	improve touch appropriateness	pre-test & post-test
	Lee et al. (2014)	ifbot	8 (11 ± 2.56)	0	achieve required force and maintain it until the end of the test	improve control of hand force with and without robot feedback	success rate

Table 2 Summary table on fine motor skills and sensorimotor rehabilitation using robots. BEERY-VMI: Beery-Buktenica Developmental Test of Visual-Motor Integration; PEP: Psychoeducational Profile; MABC: Movement Assessment Battery for Children

to improve fine motor skills of eighteen children with motor impairments (AHDH, attention deficit disorder, cerebral palsy and ASD) including five children with ASD. They underwent 15-20 daily sessions of 25-30 minutes each over 4-8 weeks. The children performed different writing tasks designed according to their writing difficulties (slowness, reversed letters...). They also performed robot-assisted glyph formation. Progress was assessed with the BEERY-VMI test. For the ASD children, progress was observed in writing speed and letter reversal. The therapy was however ineffective for children under age 9.

Moorthy et al. (2016) developed a shoe-like robot to teach ASD children to recognize left and right shoe and improve fine motor skills when closing a velcro band. When properly closed, positive visual feedback was provided. They tested the system with eight ASD children over four consecutive daily sessions. They performed pre-tests and post-tests which consisted in identifying real shoes, recognizing the left and right one and closing the velcro band. They observed improvements in this everyday task.

4.4 Sensorimotor Skills

Robins and Dautenhahn (2014) used the Kaspar robot to teach appropriate tactile behavior. The children could explore touch and interaction and were able to perform inappropriate behavior. The robot reacted to touch and indicated inappropriate behavior or hurtful contact. The authors observed that the children became more aware of their force and started paying attention to their actions.

Costa et al. (2015) also used a robot to teach eight ASD children, across seven sessions of ten minutes, how to use the appropriate force when physically interacting with a partner and the awareness of their body parts. The robot successfully acted as mediator and they observed increased triadic interaction. Inappropriate force also decreased compared to the first session.

Lee et al. (2014) designed a study to improve control of hand force using a sphere which could change colour. Eight children had to apply the required force and maintain it until the end of the test. They performed the experiment with and without feedback from the ifrobot. The experimenters observed success rate as well as target keeping. Authors reported that children performed better with robot feedback.

5 Conclusion

In this paper, we reviewed robot-based motor rehabilitation for ASD children. We remark that most therapeutic studies are focused on improving emotion or social skills. While those are obviously an issue and should be extensively studied, motor skills should not be neglected since they are directly correlated with severity of communication skills and hence of ASD and DCD is indeed a prominent comorbidity of ASD. However, so far, there are very few sound studies proposing a therapy to improve motor skills.

Here is a list of the shortcomings that could be observed:

- The studies are studies on small groups of children (average: 9.27 ± 5.52)
- Vast heterogeneity in the process and the results making it extremely difficult to compare or evaluate
- Dubious choice of evaluation methods when clinical motor assessment tests exist. These tests should be performed before the intervention, at regular intervals during the intervention and at the end of it
- No use of control group or evaluation on typical children. One group should interact with the robot and another undergo another form of therapy to sensibly demonstrate that robot-therapy for motor rehabilitation is more effective than usual methods
- It is rarely taken into account whether the children already have another treatment and how it might affect the motor therapy
- There is seldom a follow-up to check if the skills have been retained

Moreover, while many studies observe children behaviour and assess deficits, few propose a therapy. There exists several possibilities for motor rehabilitation, such as exercise therapy, rhythm therapy, occupational therapy, technology-based therapy (augmented reality, virtual reality...). However few seem to be exploited to their full extent. Indeed, while there is a significant amount of research in motor rehabilitation for stroke, spinal cord injuries, Parkinson or cerebral palsy, those studies rarely extend to ASD. Despite compelling arguments (Janzen and Thaut, 2018; Tryfon et al., 2017; LaGasse and Hardy, 2013b; Jamey et al., 2019), rhythm rehabilitation still is dauntingly underdeveloped for ASD. It has indeed been observed that despite cerebellar abnormalities, individuals are still capable of motor entrainment and synchronization. Moreover, engaging in short rhythmic motor activities leads to brain plasticity and involves structural and functional changes in the brain (Luft et al., 2004). In spite of a regain of interest in the last few years, motor rehabilitation for ASD is also still particularly neglected in the robotics field and would benefit from more rigorous methodology and from scientists willing to involve themselves in that problematic. Even when the research aims to help and improve skills, it seldom has a clearly identified goal and it is rarely methodologically sound. Indeed, most experiments have very few subjects, no control groups and no follow-up test to evaluate improvement. A lot of studies also rely only on parent questionnaires and have no objective assessment despite the existence of recognized tests such as the BOTMP. Finally, it is very hard to quantify efficiency since other interventions underwent by the children at the same time are not always taken into account and there is rarely long-term control. While most studies inspire themselves from ABA or TEACCH, few combine exercise therapy, rhythm therapy or even occupational therapy with robots. We understand that exercise or occupational therapies might be complicated due to robot limitations but we feel that combining the efficacy of rhythm rehabilitation and the engagement ASD children have with robots may be a very promising perspective.

Finally, most research employing robots is robot-centered and focuses on what design, which features to endow the robot with. This perspective was not reviewed. We do not think that the design of the robot is the most paramount aspect of the problem since children react similarly to a theatrical robot or to an actual robot. However, Srinivasan et al. (2015) suggested that children could get bored due to robot technical limitations. Robot-oriented research is also an important aspect but a lot is already being done in this field. Instead of focusing on making an engineering contribution, it is high time research was oriented towards a more human goal.

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