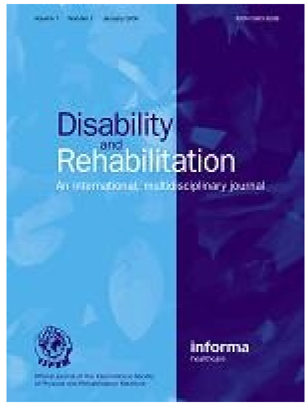

The Use of Robots for Augmentative Manipulation during Play Activities among Children with Motor Impairment: A Scoping Review

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Implications for rehabilitation

- The use of robots for augmentative manipulation during play activities may have a positive influence on the cognitive functions and the engagement in activities of children with severe motor impairments.
- Through manipulative robots, this population could be able to show the abilities that are hidden due to their motor impairments, and subsequently, receive educational and physical training more aligned with their real capacities and potential.

The Use of Robots for Augmentative Manipulation during Play Activities among Children with Motor Impairment: A Scoping Review

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ABSTRACT
Purpose: To describe the extent, type, and quality of studies involving robots for augmentative manipulation during play by children with severe motor impairments (CwSMI), and to explore how they influenced children's cognitive skills and engagement.

Methods: Web of Science, Scopus, PubMed & EBSCO were systematically searched for articles published until March 2021, that reported cognitive skills and/or engagement outcomes from interventions involving the use of robots in play activities, where participants included CwSMI, and full-text was available. Data extracted comprised characteristics of participants, study design, purpose of the study, outcomes assessed, collection methods, and intervention carried out (robot-environment interaction and robot used).

Results: Eight mobile robots and five robotic arms were reported in the 17 included and reviewed articles. Most of them informed a positive impact on CwSMI's cognitive skills and/or engagement. However, the studies scored poorly on a five-criteria quality assessment, and only one single-case design proved strong evidence of treatment. None of the analysed interventions was an evidence-based practice.

Conclusion: The use of manipulative robots during play activities may have a positive impact on the CwSMI's cognitive skills and engagement in activities. However, further studies with higher internal and external validity are needed to support stronger evidence.

KEYWORDS
Human-robot interaction; augmentative manipulation; play activities; children with disability; motor impairments; cognitive skills

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- The use of robots for augmentative manipulation during play activities may have a positive influence on the cognitive functions and the engagement in activities of children with severe motor impairments.
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1. Introduction

The International Classification of Functioning, Disability and Health for Children and Youth (ICF-CY) developed by the World Health Organization (WHO) is a conceptual framework commonly used for investigating participation in children, and classifies play as one of the most important aspects of children's quality of life [1]. Play promotes healthy habits by engaging children in the world around them [2] and it is considered a fundamental right of every child [3]. It is a natural stress reliever and allows children to work through their anxiety and fears [4], to perform different goal-oriented tasks, to make choices and decisions [5,6], to develop new higher-order representations [7], and to understand the cause-effect relationships and the chaining of sequences of thoughts [8], among other things. This highlights the importance of making play activities accessible for every child.

Although it is relatively easy to observe and describe, the concept of "play" characterises a complex and multifaceted behaviour that is difficult to define theoretically [9]. Extensive attempts to define "play" can be found in the literature [10], but we have adopted Garvey's definition [11], as proposed by the LUDI network [12]: "Play is a range of voluntary, intrinsically motivated activities normally associated with recreational pleasure and enjoyment".

Choice has been identified as one of the most important elements of a playful environment, along with elements of self-direction and spontaneity, all of which must be considered by therapists and teachers to assist children to develop self-initiation, intrinsic motivation, spontaneity, social skills, decision-making, and a sense of self-worth, among others [13].

Children with severe motor impairments (CwSMI) such as cerebral palsy (C.P.), acquired brain injury, or muscular diseases may specially experience difficulties with autonomous object manipulation [14]. This can result in decreased (or even a complete lack of) opportunities to interact with their environment during the early stages of their development [15], and as a consequence, their engagement in activities of daily living, including free play and academic activities [16,17], may become weakened. For example, a child with mild C.P. may not have enough hand dexterity, and therefore be unable to manipulate toys as desired, while another more severely impaired child may be further unable to express or communicate his or her interest in a toy [9]. In short, the inability to manipulate the environment at will results in a lack of chances to make choices, which results in a lack of play. Moreover, due to the early onset of some pathologies involving motor impairments, the reduction of physical interaction opportunities can result in further secondary conditions such as cognitive development delay, learning deficits, social skill issues, or low self-esteem and self-efficacy [8,18].

In order to manipulate their environment at will, children and adults with poor hand dexterity due to severe motor impairments need to find alternative manipulation means besides directly using their hands or other parts of their bodies. An augmentative manipulation system supplements (augments) the existing manipulation skills of the user and compensates for limitations in manipulation [19]. Robots can be used as augmentative manipulation tools due to their ability for picking, placing and exploring objects [20]. Examples of specifically designed augmentative manipulation robots are: robotic (arm) manipulators, either attached to a wheelchair [21] or attached to fixed structures like a desktop [22], or mobile robots [23]. Tejima further identified examples of workstations, robotic orthoses and robotic rooms for augmentative manipulation [20].

The use of robots as augmentative manipulation tools can be particularly beneficial for CwSMI to interact with their environment in a similar way to their peers [24,25]. However, the manipulation mediated by a robot is not the same as manipulating objects with hands. It can add additional cognitive effort to the task [26], which can result in poor robot operational competence, which could be confused with poor performance on the task. Hence, robots may help with the motor task while at the same time increasing its cognitive complexity [27].

The increasing use of robots to promote autonomous play in CwSMI for rehabilitation and education purposes is an emerging field of research, and other literature reviews have been compiled about this topic. For instance, the review led by van den Heuvel et al. [28] described the aims, control options and commercial availability of information and communication technology and robots to support play in children with severe physical disabilities. Another review, led by Bayon et al. [29], focused on the impact on rehabilitation outcomes, and reported results from robot-assisted therapies designed for people with C.P., focusing on lower and upper limb rehabilitation. Another example is the review performed by Miguel Cruz et al. [30], which examined the types of robots used with children and young people with C.P. and autism spectrum disorder. However, the information provided on these reviews about the activities carried out during the interventions was limited, and the robots employed on them were not necessarily physical nor aimed to promote the augmentative manipulation.

Through this scoping review, we aim to provide comprehensive information that characterises the state of the art of interventions developed using robots for augmentative manipulation during play activities among CwSMI, and how these interventions influenced the cognitive skills and engagement in activities of the children involved.

2. Methods

The scoping review approach of Levac, Colquhoun, and O'Brien [31] was used as a guide to conduct this review. The procedure starts with a systematic search of the published literature involving the use of robots for augmentative manipulation during play by CwSMI; then mapping the characteristics of the identified studies, including study design, population, and quality level; and finally, identifying key elements regarding the influence of those robots on children's cognitive skills and engagement in activities. In addition, to ensure the inclusion of all the required information for this type of study, the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist was employed [32].

2.1. Identifying the Initial Research Question

The aim of this scoping review was to identify the landscape of studies involving CwSMI and interventions with robots for augmentative manipulation in play activities using the following research questions:

RQ1. What are the extent and the type of studies about interventions developed using robots for augmentative manipulation during play activities among CwSMI?
RQ2. Are the developed interventions influencing the cognitive skills and engagement in activities of CwSMI?
RQ3. What is the quality of these studies?

2.2. Identifying Relevant Studies

The electronic databases Web of Science (WoS), Scopus, PubMed, and EBSCO, were searched for articles published up until March 17, 2021, including journal articles, conference proceedings, books, and book chapters, available in English or Spanish. The search terms used were: "child*" AND "play*" AND "robot*" AND ("phys* disab*" OR "motor disab*" OR "phys* impair*" OR "motor impair*").

The inclusion of these search terms was discussed by the heterogeneous group of authors (including two computer engineers and an occupational therapist).

Publications were included if they met five criteria: (a) participants or a subgroup of participants were children (i.e., aged younger than 18 years) with motor impairment(s), understanding motor impairment as the partial or total loss of function of a body part; (b) results reported came from an intervention developed using physical robots (i.e., a physically present agent, operating in a physical world) for augmentative manipulation of the environment, considering augmentative manipulation as the way to manipulate and interact with the same objects as their peers that can supplement or compensate for the impairment and disability patterns of individuals with motor impairments; (c) the interventions contained a play component, considering Garvey's definition of play [11]; (d) the publication reported outcomes related to cognitive skills (i.e., those involved in thinking, listening, learning, understanding, justifying, questioning, and paying attention) and/or engagement in activities (i.e., the behavioural intensity and emotional quality of a person's active involvement during a task [33]); and (e) full-text was available.

2.3. Study Selection

The database search and the initial removal of duplicates were carried out by one reviewer. The relevance of the remaining publications was assessed in two phases. In a first phase, two reviewers independently assessed the eligibility of the publications by comparing the data provided on the titles and abstracts with the proposed inclusion and exclusion criteria. In a second phase, the full-text of the previously selected publications was read and independently assessed by the same two reviewers to determine their suitability for inclusion in the data extraction phase, by using the same criteria as for the previous phase.

To check for the reliability of the study selection, the relevance of the publications was scored at phases one and two by both reviewers on a 3-point scale (0 = not relevant, 1 = doubtful, 2 = relevant). If the two reviewers' results matched, this was coded as an agreement. If results between the two reviewers did not match, this was coded as a disagreement. Disagreements were resolved by discussing discrepancies until agreement was reached. However, if the agreement was difficult to reach, a third author provided a final decision. Simple percent agreement (calculated by dividing the sum of agreements by the total number of agreements plus disagreements multiplied by 100) and Cohen's kappa were calculated at both phases. Percent agreement above 80 % and Cohen's kappa values above .60 would be considered acceptable [34].

2.4. Data Extraction

Included articles were reviewed, and descriptive information was extracted for coding. To identify common themes and research gaps within the reviewed articles, a standard spreadsheet was developed. Each article was coded for the following attributes (if available): year of publication; authors' affiliation; country; study design; sample size; participants' sex, chronological age and diagnosis; characteristics of the robots used in the interventions (name, type, and control options); specific manipulative activity performed by the robot in the environment; outcomes assessed; characteristics of the interventions (length in years/months/weeks, phases, number of sessions, session duration in minutes/hours and setting where the robot was tested (i.e., laboratory, hospital/rehabilitation centre, school, home, or other)); type of professionals involved in the intervention; and the results obtained.

The information pertaining to the type of the robots used in the interventions and outcomes assessed was placed into categories, identified by the reviewers. New categories were added when a type of robot and/or outcomes assessed were identified that did not fit into an existing category.

Studies were classified according to their design as single-case design (SCD), pre-experimental SCD, or non-randomised controlled trial design. The guidelines presented on the "What Works Clearinghouse - Single-case design technical documentation" [35] were followed to classify the studies as SCD. A study was considered SCD if (a) the unit of intervention and the unit of data analysis was an individual case (i.e. a single participant or a cluster of participants); (b) the case provided its own control for purposes of comparison; and (c) the outcome variable was measured repeatedly within and across different conditions or levels of the independent variable. If a study met the criterion (a) but did not meet (b) and/or (c), it was classified as a pre-experimental SCD.

To check for the reliability of the extracted data, first, two reviewers discussed upon agreement the coding used for the extraction. After the data were independently extracted by both reviewers, results were compared and discussed. Reliability on data extraction was 100 % for percent agreement and Cohen's kappa. Finally, the results from data extraction were summarised.

A five-criteria study quality assessment (adapted from Khan et al. [36]) was used to assess the quality of the included studies. The five criteria of quality assessment comprised were: (1) Is the study based on a representative sample selected from a relevant population?; (2) Are the criteria for inclusion explicit?; (3) Are the cases and controls comparable with respect to potential confounding factors?; (4) Was an appropriate statistical analysis used (matched or unmatched)?; and (5) Were the outcomes assessed using objective criteria?

The quality of SCD studies was additionally assessed. To meet design standards, the study must report information about (1) the systematic manipulation of the independent variable; (2) the systematic measurement of each outcome by more than one assessor (including information about the inter-assessor agreement in each phase (must be documented on the basis of an accepted psychometric measure of agreement, such as the percentage agreement and Cohen's kappa coefficient, and on at least twenty percent of the data points in each condition); (3) the inclusion of, at least, three attempts to demonstrate an intervention effect each at a different point in time; and (4) the inclusion of a minimum of three data points per phase. Those that met design standards were assessed using the evidence criteria to determine whether there was evidence of treatment effect (evidence of the relationship between an independent variable and an outcome variable). Studies with a strong evidence of treatment must report (1) the consistency of level, trend, and variability within each phase; (2) the immediacy of the effect, the proportion of data overlap between phases, the consistency of the data across phases; and (3) examination of external factors and anomalies [35].

The evidence-based practice (EBP) of the interventions was assessed by applying the criteria developed by the National Professional Development Center on Autism Spectrum Disorder [37]. An intervention was considered to be an EBP if there were: (1) two high quality experimental or quasi-experimental group design studies conducted by at least two different researchers or research groups; (2) five high quality single subject design studies conducted by three different investigators or research groups, having a total of at least 20 participants across studies; or (3) one high quality randomised or quasi-experimental group design study and at least three high quality single subject design studies conducted by at least three different investigators or research groups (across the group and single subject design studies).

The quality assessment process (including the five-criteria quality assessment, the specific quality assessment of SCD studies, and the assessment of EBP of the interventions) was completed independently by two reviewers. Any disagreements between the two reviewers were resolved by discussion until a consensus was reached. Reliability on quality assessment was 100 % for percent agreement and Cohen's kappa.

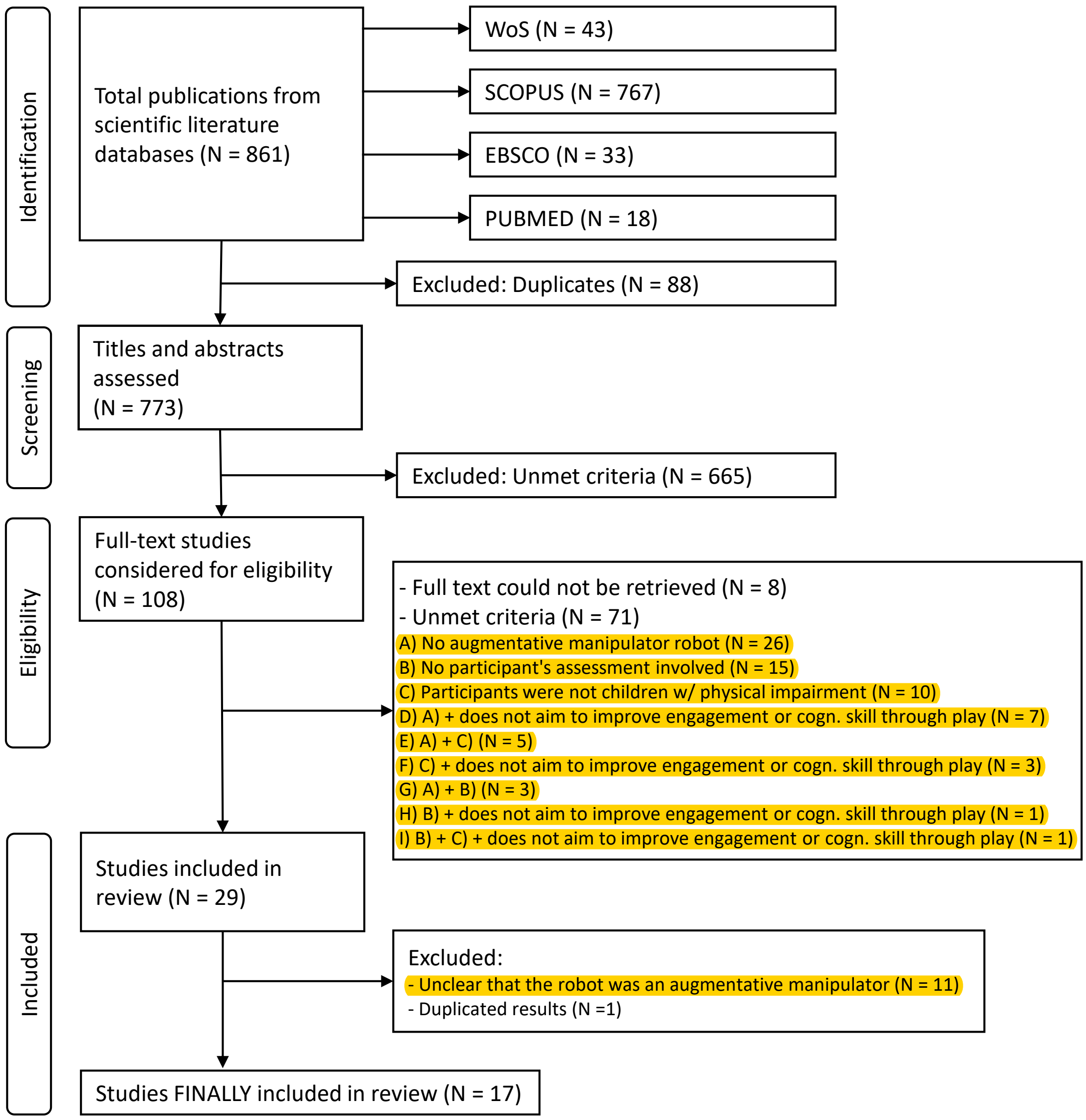
3. Results

3.1. Study Selection

A total of 861 articles were identified with the search terms (figure 1). After removing duplicates, 773 went through the title and abstract review and yielded 108 articles for full-text review. The 108 articles were searched for full-text, and 29 were considered for data extraction. Nevertheless, the reviewers agreed during the process that in 11 of them it was not certain whether the robot employed in the intervention was manipulating the environment. In addition, the results reported in one of the articles were duplicated from another already included. Finally, 17 articles were included and considered for data extraction. The level of agreement between the reviewers was near perfect, i.e., 98 % average agreement for titles and abstracts (Cohen's Kappa score of 0.94), and 99 % average agreement for full-text articles (Cohen's Kappa score of 0.98).

[INSERT FIGURE 1 NEAR HERE]

Figure 1.: Flow chart article selections



3.2. Description of the Studies (extension and type)

Of the 17 included studies, 12 were journal articles, three were conference proceedings, and two monographs. They took place in seven different countries. Almost one-third of the studies (29.4 %) were conducted in Canada, followed by the USA, Austria and Colombia, each of them accounting for 11.8 % of the studies; and Denmark, Portugal and Sweden, each accounting for 5.9 % of the studies. In 17.6 % of the studies, there were international collaborations (two of them between Canada and Portugal, and one between Colombia and Canada). Although the oldest was published in 1988 [38], most of the studies (64.7 %) were published between 2011 and 2020.

Table 1 shows a summary of the included studies characterising the participants (N, diagnosis, and age), methodology (study design, purpose of the intervention, outcomes assessed, and collection methods), and intervention carried out (performed robot-environment interaction and robots used).

[INSERT TABLE 1 NEAR HERE]

3.2.1. Participants

The included studies involved between 128 and 138 children in total (one of the studies did not specify the exact number of participants, providing only a range), and were characterised by low sample sizes (mean = 7.5, SD = 6.9, range = 1 − 29). Among the eight studies that reported the participants' sex, there was a distribution of 14 boys to 10 girls. Only 12 studies reported the chronological age of each participant (one of them only reported it for the case group), one reported the chronological age ranges, one just the cognitive age ranges, and three did not provide this data (one of them just reported that the children were less than 36 months old, and another one that the participants were adolescents). In eight studies, the age difference between the youngest and the oldest participant was greater than 30 months. In table 1, age was reported in months for standardisation purposes. Between 96 − 106 children had physical impairments, and 32 were children without physical impairments, from control groups or playmates. Regarding the diagnoses of the participants with impairments, it was explicitly stated in eight studies that the sample was composed of participants with C.P., in four it was explicitly stated that the sample was composed of participants with C.P. and participants with other pathologies, and in three the specific diagnoses were not stated or they were ambiguous. In addition, 15 studies reported that the participants had a range of speech difficulties, and nine explicitly stated that all or some of the participants had cognitive and/or intellectual impairments. However, only eight studies used standardised measures to characterise the participants. To measure the motor function, the most frequently used tool was the Gross Motor Function Classification System (in five studies), followed by the Manual Ability Classification System (in three studies). Cognitive age was mostly measured with the Pictorial Test of Intelligence (in four studies), and language abilities were mainly measured with the Peabody Picture Vocabulary Test (two studies), the Communication Function Classification System (one study), or the Reynell developmental language scales (one study).

3.2.2. Study Design

Eight studies followed an SCD, five of which applied a changing criterion [39–43], one applied multiple baselines [23], another one alternating treatments [44], and another one both alternating treatments and changing criterion [45]. Five were pre-experimental SCD studies [46–50], and four were non-randomised controlled trial design [38,51–53].

Table 1.: Summary of the included articles characterising the participants, methodology, and intervention carried out.

Type of outcomes	Study	Participants	Methodology	Intervention & Robot (control options)
Mobile robots				
Cognitive skills	Adams & Encarnação (2011) [39]	3 with spastic-athetoid, quadriparetic C.P. Age: x̄ = 144, SD = 24.0, range = 120-168**	Study design: Single-case design: Changing criterion. Purpose: To describe a training protocol to control Lego robots via SGDs. Outcomes assessed: Ability to control the robot (Success at knocking over the blocks, accuracy of the trajectory performed by each participant, difficulty experienced, and time to complete the slalom trails). Collection methods: Direct observation.	Intervention: Avoid obstacles while (1) picking & placing blocks; (2) lifting or lowering the side-mounted pen when passing obstacles; or (3) to make a dotted line. Robot: L.M. Schools kit with a Gripper (SGD & switches)
	Cook et al. (2011) [40]	10 with C.P. and related motor conditions Age: x̄ = 99, SD= 26.8, range = 52-125	Study design: Single-case design: Changing criterion. Purpose: To investigate the use of robotic play as a means of assessing the level of their cognitive skills. Outcomes assessed: Cognitive skills to control the robot, based on the Forman classification (Level 0. No interaction, Level 1. Causality: Understanding the relationship between a switch and a resulting effect, Level 2. Negation: An action can be negated by its opposite, Level 3. Binary logic: Two opposite effects such as on and not on, Level 4. Coordination of multiple variables: Movement in more than one dimension to meet a functional goal, Level 5. Symbolic play: Make believe with real, miniature or imaginary props, Level 6. Problem solving: Problem solving with a plan – not trial and error, generation of multiple possible solutions), as well as behavioral, social and language changes. Collection methods: Direct observation, and post-intervention interviews with teachers/teacher assistants.	Intervention: Perform symbolic play, and problem solving. Robot: L.M. Invention "Roverbot" (Switches)
	Encarnação et al. (2014) [45]	Cases: 9 with C.P. Cognitive age: 5 between 33-39, 2 between 45-51, 2 between 57-63 Reference group: 20 without disability Cognitive age: 5 between 33-39, 8 between 45-51, 7 between 57-63	Study design: Single-case design: Alternating treatments and Changing criterion. Purpose: To determine if the tasks successfully completed by children without disability using physical robots are also successfully completed using computer simulations of robots; if the tasks successfully completed using physical robots by children with disabilities are also successfully completed using computer simulations of robots; and the potential for the tasks to discriminate children by cognitive age. Outcomes assessed: Behavioural changes (child rejects the activity, fatigue, stereotypes, and echolalia), and interaction and communication (search for support, additional guidance, child's comments, verbal and non-verbal expressions of displeasure and of pleasantness)), and cognitive skills (sustained attention, association of ideas, visuospatial and temporal perception, eye-hand coordination, and self-regulation/impulsivity). Collection methods: Direct observation.	Intervention: Knock over a stack of blocks. Robot: L.M. TriBot (Switches)

Type of outcomes	Study	Participants	Methodology	Intervention & Robot (control options)
Mobile robots				
Cognitive skills	Adams & Cook (2016) [41]	1 with spastic-athetoid, bilateral C.P. Age: 144**	Study design: Single-case design: Changing criterion. Purpose: To examine the participant's use of an SGD in various hands-on academic activities; to determine the competencies needed to use an SGD to control a robot in these activities; and to establish if the participant and teacher were satisfied with the SGD-robot activities involved in the study. Outcomes assessed: Ability to control the robot (accuracy), and communication events and rate. Collection methods: Direct observation, and post-intervention interview with the user.	Intervention: Draw with a marker attached to the robot; move across the board games; put together puzzle pieces; draw by connecting-the-dots; and act out a story with the robot. Robot: L.M. RCX with a Robotic arm (SGD & switches)
	Encarnação et al. (2017) [51]	"Physical robot group": 6 5 with C.P. and 1 with global development delay Age: x̄ = 56.2, SD = 12.1, range = 43-74 "Virtual robot group": 3 2 with C.P. and 1 with traumatic brain injury Age: x̄ = 71.3, SD = 4.0, range = 67-75	Study design: Non-randomised controlled trial design: Pretest-posttest with repeated measures on increasingly difficult activities. Purpose: To evaluate academic achievement when using the IAMCAT compared to performance before intervention; to assess teachers' perceptions of the use of the IAMCAT and its impact on the student and in the classroom; and to compare virtual and physical robotic systems in relation to objectives 1 and 2. Outcomes assessed: Ability to control the robot (accuracy and level of prompting required), and operational competence using the access method on the SGD (accuracy and time to select target items on the SGD). Collection methods: Direct observation, and pre and post-intervention semi-structured interviews with teachers.	Intervention: Drive robot into stacks of blocks to avoid obstacles, pick & place objects, and trace lines using an attached pen. Robot: L.M. NXT IAMCAT with a Gripper (SGD, switches & eye gaze)
	Acevedo-Londono et al. (2019) [53]	Cases: 2 1 with spastic C.P. and 1 with hemiparesis and hypotonia in upper limbs Age: x̄ = 174, SD = 42.4, range = 144-204** Controls: 2 with hemiparesis Age: x̄ = 168, SD = 17.0, range = 156-180**	Study design: Non-randomised controlled trial design: Pretest-posttest with repeated measures on increasingly difficult activities. Purpose: To evaluate the effectiveness of SpinBOT environmental therapy for upper limb rehabilitation. Outcomes assessed: Ability to control the robot (number of times the switches were pressed, success at knocking over the blocks, and time spent on each try). Collection methods: Direct observation, and post-intervention interviews with users and teachers/therapists.	Intervention: Knock over a stack of blocks, avoiding obstacles. Robot: SpinBOT (Switches & didactic glove instrumented with an accelerometer)

Type of outcomes	Study	Participants	Methodology	Intervention & Robot (control options)
Mobile robots				
Engagement	Spiegel-McGill et al. (1989) [44]	Cases: 4 with orthopaedical impairments Age: x̄ = 58.8, SD = 3.0, range = 55-62 Playmates: 4 without disability Age: not reported	Study design: Single-case design: Alternating treatments. Purpose: To test the engagement effects of the computer and the robot, and to compare these activities to a baseline condition where children generally had to play with each other; and to assess differential effects across the activities based on the social competence of peers engaged in those activities. Outcomes assessed: Occurrence of socially directed behavior. Collection methods: Direct observation.	Intervention: Manipulate two objects in a tray. Robot: Robbie Junior (Switches)
	Ríos-Rincón et al. (2013) [46]	1 with spastic C.P. with quadriplegia Age: 55	Study design: Pre-experimental AB design (pilot study). Purpose: To investigate the effect on a child's level of playfulness in a home-based robot intervention that promotes free play. Outcomes assessed: Child's playfulness.	Intervention: Perform symbolic play, and problem-solving. Robot: L.M. Invention "Roverbot" with a Shovel (Switches)
	Ferm et al. (2015) [47]	2 triads of a child with C.P., a peer playmate without disability & adult support playmate Age: 2 Children with C.P.: x̄ = 65.5, SD = 17.7, range = 53-78; 2 Peer playmates: x̄ = 59.5, SD = 12.0, range = 51-68	Study design: Pre-experimental only-tratment design. Purpose: To explore how is participatory symmetry between children with complex communication needs and their peers achieved in interaction with LekBot; and in what sequential contexts do the children display enjoyment when interacting with LekBot. Outcomes assessed: Engagement (participation in play with the LekBot system, with each other, and with the adult support person through body movements and with speech and language, as well as how and when affect was displayed) and enjoyment (smiles and laughter, in combination with body orientation and movements, gestures, and eye gaze). Collection methods: Direct observation, and post-intervention interviews with pre-school staff and users.	Intervention: Perform symbolic play. Robot: L.M. NXT 2 LekBot (Touch-screen computer)
	Ríos-Rincón et al. (2016) [23]	4 with C.P. Age: x̄ = 90, SD = 23.1, range = 65-112	Study design: Single-case design: Multiple baseline. Purpose: To investigate the effect of a robotic intervention on the playfulness of children with cerebral palsy. Outcomes assessed: Child's playfulness, and social validation of change.	Intervention: Knock over a stack of blocks. Robot: L.M. Invention "Roverbot" with a Scoop (Switches)
	Mariager et al. (2019) [48]	3 with C.P. Age: adolescents, exact age not reported	Study design: Pre-experimental only-tratment design. Purpose: To analyze social interactions between players. Outcomes assessed: Social interaction between participants: initiations (possible start to an interaction between the players of a game), responses (following an initiation from the other player), concurrents (interactions (verbal or non-verbal) following an initiation and response). Collection methods: Direct observation.	Intervention: Hit the correct cone, placed in front of the players. Robot: TurtleBot3 Burgers (Joystick with 4 control modes with increasing difficulty)

Type of outcomes	Study	Participants	Methodology	Intervention & Robot (control options)
Mobile robots				
Cognitive skills & Engagement & Physical skills	Acevedo-Londono et al. (2018) [52]	Cases: 2: 1 with spastic C.P. and 1 with hemiparesis and hypotonia in upper limbs Age: x̄ = 174, SD = 42.4, range = 144-204** Controls: 2 with hemiparesis Age: x̄ = 168, SD = 17.0, range = 156-180**	Study design: Non-randomised controlled trial design: Pretest-posttest with repeated measures on increasingly difficult activities. Purpose: To evaluate the effectiveness of SpinBOT environmental therapy for upper limb rehabilitation. Outcomes assessed: Ability to control the robot, movement ranges of upper limbs, and enjoyment. Collection methods: Direct observation.	Intervention: Knock over a stack of blocks, avoiding obstacles. Robot: SpinBOT (Switches & didactic glove instrumented with an accelerometer)
Robotic arms				
Engagement	Kronreif et al. (2005) [49]	First trials: 3 without disability Age: 60-84** Second trials: 3: 1 with multiple physical impair., 1 with tetraparesis and 1 with transverse spinal cord synd. Age: 108-132**	Study design: Pre-experimental only-treatment design (feasibility study). Purpose: Acceptance of the system and intuitiveness of the user interface concept. Outcomes assessed: Acceptance of the system and intuitiveness of the user interface concept. Collection methods: Direct observation.	Intervention: Manipulate small Lego bricks. Robot: PlayROB (Dedicated input devices for AT: joystick, 5-key input device, single switch, etc.)
Cognitive skills & Engagement	Cook et al. (1988) [38]	Cases: 6 with developmental delay Age: less than 36 Controls: 3 without disability Age: matched with cases	Study design: Non-randomised controlled trial design: Repeated measures within and between case-control subjects, on increasingly difficult activities. Purpose: To create a learning environment for young children with disabilities which mimics the world of the children without disabilities as closely as possible. Outcomes assessed: Detection of behaviors (directing eye gaze to the object being controlled or to the screen, looks at switch, unaware of contingency, looks of contingency, switch activations, robotic arm movement actions controlled, time of occurrence along with the coded behavior, shows interest, expressing fear, interest, boredom, etc). Collection methods: Direct observation.	Intervention: Retrieve an object in view of the child but out of reach. Robot: MiniMover-5 robotic arm (Switches or other adapted input)

Type of outcomes	Study	Participants	Methodology	Intervention & Robot (control options)
Robotic arms				
Cognitive skills & Engagement	Cook et al. (2000) [42]	4 with C.P. Age: x̄ = 78, SD = 6.9, range = 72-84**	Study design: Single-case design: Changing criterion. Purpose: To determine if (1) the child appeared to relate each switch to its corresponding action, (2) the child took a role in the play activity, and (3) the child could combine the switch actions into a three-step process; and to examine the quality of this type of play experience for children with physical abilities and whether these children would learn to engage in turn-taking behavior that involved manipulation of objects in a co-operative play situation with an adult. Outcomes assessed: Ability to control a robotic arm to engage in functional play tasks (relationship of each switch to its corresponding action, child's active role in the play activity, and ability to combine the switch actions into a three-step process), and type and number of prompts required in order for the child to successfully complete the task. Collection methods: Direct observation.	Intervention: Dig an object out of macaroni and dump macaroni and objects. Robot: Robotic arm CRS A465 (Switches)
	Cook et al. (2005) [43]	12 with spastic quadriplegia (athetoid in one of them). 4 also had seizure disorder (in one of them combined with visual impairment and in another with West syndrome); and 2 had G-tube, in one of them in addition to visual impairment. Age: x̄ = 119, SD = 31.7, range = 60-168**	Study design: Single-case design: Changing criterion. Purpose: To evaluate how children with severe physical disabilities can physically control a robotic arm to engage in functional play tasks; and to determine the impact of the use of a robotic arm on children's behavior, social and academic performance, including play and emergent literacy skills. Outcomes assessed: Ability to control the robot (number and time of occurrence of prompts (visual/auditory), incorrect switch hits, and attention to task (looking at the robot, looking at the teacher, not attending to task)), and carryover to the classroom. Collection methods: Direct observation, and post-intervention interviews with teacher.	Intervention: Dig an object out of macaroni and dump macaroni and objects. Robot: Rhino XR-4 Robot Arm (Switches)
	Kronreif et al. (2007) [50]	17-27 with significant physical and cognitive impairment Age: not reported	Study design: Pre-experimental only-treatment design. Purpose: To open access to common toys for children with different kinds of physical disabilities by means of uptodate (robot) technology. Outcomes assessed: Impact of the design and learning effects (duration of playing session, number of used bricks and number of different brick types, time required for brick placement, utilization of the playground area). Collection methods: Direct observation, and post-intervention interviews with teacher/therapists.	Intervention: Manipulate small Lego bricks. Robot: PlayROB (Standard input devices for AT: joystick, 5-key input device, single switch, etc.)

L.M. = Lego MindStorms ®

* All ages are chronological ages unless otherwise stated.

** The number of months is not exact due to the authors just provided the chronological age in years.

3.2.3. Characteristics of the Interventions

Four studies were conducted in education centres [41,43,44,47]. Two were conducted in rehabilitation centres [52,53], one in the participants' home [46], and five in more than one place (29.4 %) [23,45,48,50,51]. The settings were not reported in five studies. The information regarding the professionals involved in the interventions was reported in 14 studies, and these were mainly teachers (in three studies), therapists (in two studies), teachers and therapists (in five studies), or others (four studies).

Eight studies [38,39,41,44,45,48,52,53] started with a period of training/familiarisation where children were taught how to move the robot (including stages of modelling and exemplification); six [40,42,43,47,49,50] started directly with the intervention, always composed of progressive tasks; two studies [23,46] started with a baseline where the children and their mothers were instructed to play together with non-robotic toys, followed by a period of training/familiarisation with the robot; and in one, the study [51] started with pre-intervention semi-structured interviews with teachers and was followed by a period of training/familiarisation with the robot. In addition, six studies [40,43,47,50,51,53] reported post-intervention interviews with the school staff (teachers, therapists, etc.), and two of them [47,53] also included interviews with users. One study [41] reported only post-intervention interviews with users. Outcome variables were collected through direct observation in all the studies.

The total length of the studies was properly described only in seven out of the 17 studies [41,43,45–47,52,53]. In these studies, the interventions took an average of 7.6 weeks (SD = 6.7, range = 2 to 20). Regarding the number of sessions, only 10 studies [40,41,44–49,52,53] reported the exact number of sessions. The average number of sessions from these studies was 8.4 (SD = 4.1, range = 2 to 14). Four studies only reported a range of the number of sessions (between 12 to 15 sessions in [43], between three to four sessions per participant in [39], between 18 to 21 sessions in [23], and between three to seven in [51]), and no such information was specified in the remaining three studies. Information about session duration was reported in 12 studies. However, only six [23,44,46,51–53] reported the duration rigorously (mean = 34.2 minutes, SD = 16.6, range = 15 to 50), while in four the authors reported a range of time (between 10 to 30 minutes in [48], 30 to 60' in [39], 20 to 60' in [47], and 23 to 65' in [41]), and two [38,42] reported that the duration of each session was up to one hour.

3.3. Type of Robots and Robot-environment Interaction

Type of robot was a theme that emerged from the thematic analysis. The total number of different robots used in the included studies was 13. The type of robots more frequently used in the interventions were mobile robots (used in 12 studies [23,39–41,44–48,51–53]), of which there were two types: (a) The Robbie Junior [44], a remote-controlled (through a button) toy robot with a tray and two small objects that allowed the children to use the robot to manipulate these objects (used in one study), and (b) vehicle-like robots. Among the latter, five were built with Lego MindStorms (three "Roverbots" [23,40,46], developed with the Robotics Invention System and controlled with an adapted infrared remote control through the activation of one or more switches; a "TriBot" [45] also controlled with switches; and a "LekBot" [47] dressed like a bumblebee and controlled with a touch-screen computer); another was "SpinBOT" [52, 53], which consisted of a didactic glove instrumented with an accelerometer, a control module, a mobile robot, and a visualisation tool; and there was also a "TurtleBot3

Burger" [48], a modular, compact and customisable robot, controlled with a joystick with five control modes with increasing difficulty to "level the playing field between the game players". In addition, three studies used robots based on a combination of a mobile robot with a robotic arm/gripper, also built with Lego MindStorms, two of them [39,41] controlled with Vanguard II Speech Generating Devices (SGDs) and one [51] with The Grid.

These kind of robots were used to (a) manipulate two objects in a tray [44]; (b) perform symbolic play [47] and problem solving [40,46]; (c) drive and knock or hit objects (such as a stack of blocks or cones) [23,45,48,52,53]; (d) avoid obstacles while driving and picking up and placing objects and drawing with an attached pen [39,41,51] or marker; (e) move game pieces to play board games; and (f) act out a story with a robot [41].

Five studies used robotic arms [38,42,43,49,50]. Two of them [49,50] used the "PlayROB" system, composed of a robot with a three-degrees-of-freedom (DOF) Cartesian configuration and a Lego bricks storing system that consists of a set of supporting rails. The other three were the "MiniMover–5" [38], the "CRS A465" [42], and the "Rhino XR-4" [43], all three of them being 5-DOF robot arms that could rotate around their base, bend (flex/extend) at the shoulder, elbow, and wrist, rotate (supinate/pronate) at the wrist, and they could also open and close their two-fingered gripper. The four robots were controlled with switches and standard or adapted input devices for assistive technology – such as a special joystick, a 5-key input device, or a mouth operated joystick – connected to a standard interface box, or movements accessed using a scanner. These kinds of robots were used to (a) retrieve [38], and dig and dump objects [42,43]; and (b) manipulate Lego bricks [49,50].

Only seven of the 13 used robots were not play objects at all and their activity was limited to serve just as a manipulation assistant, mediating the manipulation between the children and environment. These were all robotic arms, in addition to the Lego MindStorms RCX and NTX, and the TurtleBot3 Burgers.

3.4. Influence of the Interventions in CwSMI

Type of outcome assessed was another theme that emerged from the thematic analysis. In this section the main results reported in the included studies are summarised.

Among 17 studies, six focused on the assessment of the influence of the interventions in the cognitive skills of CwSMI [39–41,45,51,53], six were mainly focused on assessing the engagement of the participants in activities carried out with the manipulative robots [23,44,46–49], and five aimed to measure the influence of the intervention both on cognitive skills and engagement in the activity [38,42,43,50,52]. The six studies that measured the participants' cognitive skills [39–41,45,51,53] and five of the ones measuring participants' engagement in activities [23,44,46–48] used mobile robots in their interventions. However, four of the studies both measuring participants' cognitive skills and their engagement in activities used robotic arms [38,42,43,50].

3.4.1. Influence of the Interventions in the Cognitive Skills

Four of the six studies that focused on assessing the influence of the interventions upon the cognitive skills of CwSMI were SCD studies [39–41,45], and the other two were non-randomised controlled trial design [51,53]. The study of Cook et al. [40] showed that when some children with C.P. and related motor conditions used a Lego MindStorms Invention "Roverbot" to perform symbolic play (i.e. serving at a tea party, exchanging toys with friends, pretending to feed animals, all using robots), and problem-solving, they were able to display skills that they possessed but that may have been difficult to demonstrate in standardised tests, showing that their motor ability was not directly related to their cognitive ability. Also, most of them increased their attention to task and vocalisation and verbalisation with other children, showing enjoyment during the intervention. Moreover, teachers were enthusiastic about the potential use of the robot in the classroom. Adams et al. [39] described a training protocol to control Lego MindStorms robots "Schools kit" via SGDs, to bring the participants (children with spastic-athetoid, quadriparetic C.P.) to an adequate competency level before performing some mathematics activities. In their results, they reported that introducing domains (robot control, manipulation and communication) one at a time provided an opportunity to incrementally develop children's abilities to use the robot as a tool to perform educational mathematics measurement tasks, but children's accuracy decreased as more obstacles, manipulation, and communication requirements were progressively added to the trials. Related to the same topic, Adams et al. [41] conducted a study aimed to determine the competencies needed by the participant (a child with spastic-athetoid, bilateral C.P.) to control a mobile Lego MindStorms robot equipped with an RCX robotic arm in various hands-on academic activities. The authors reported that the participant showed sustained interest and attention while using her SGD and the robot, participating eagerly in mathematics and social studies activities, and even asking that some activities were repeated. However, this usage was influenced by activity type (it was lower when the activity required more action-focused activities demanding more robot manipulation). Nevertheless, both the participant and her teacher expressed satisfaction with robot use.

Two studies compared the impact of the intervention when using a physical and a virtual version of the robots. The first study, conducted by Encarnação et al. [45], compared the success rate of children with C.P. when performing the tasks (knocking over a stack of blocks) with Lego MindStorms "TriBot" robots and with a computer simulation of a matching virtual version. They reported that the success rates were similar for the two versions, and found significant differences in visuospatial and temporal perception, with children with C.P. performing better with the virtual robot. The use of these tasks may be able to discriminate between children by cognitive age, although this evidence is inconclusive from the obtained results. No significant differences between the physical and virtual robots were found regarding self-regulation. The second one, a study conducted by Encarnação et al. [51], aimed to evaluate the impact of an intervention developed by using a Lego MindStorms NXT "truck-like robot" with a gripper, on academic achievement of children with C.P., Global development delay, and Traumatic brain injury. They found that teachers' opinions on academic achievement refer more commonly to unsatisfactory academic performance when using the physical robotic system compared with the virtual version, but there were no clear differences regarding the appreciation of the pedagogical process between the physical and the virtual robot. Teachers stated that, in general, the intervention had a positive impact on the participation, motivation and autonomy of some participants, and on the educational community, promoting manipulation, communication, and learning.

3.4.2. Influence of the Interventions in the Engagement in Activities of CwSMI

Regarding the six studies focused on assessing the engagement of the participants in activities, four were pre-experimental SCD studies [46–49], and two were SCD studies [23,44]. One example is the study designed by Spiegel-McGill et al. [44], who found similar social interactions when children with orthopaedic impairments played with their special friends (children without disabilities) in three different conditions: (1) A microcomputer set up for use, with a remote-controlled robot (Robbie Junior model) available, but turned off; (2) a remote-controlled robot set up for use, with a turned-off microcomputer present; and (3) both activities available, but turned off. However, interacting with the microcomputer resulted in more socially directed behaviours within the dyads composed of participants with significant social, language, and physical limitations. There were no differences across the three conditions in the dyads in which the children had mild social interaction. Ferm et al. [47] also focused on engagement and measured the participatory symmetry between children with disabilities (C.P. and complex communication needs) and their peers when performing symbolic play (i.e. searching for, finding, and eating symbolic food) with the robot "LekBot". They found that neither participatory symmetry nor enjoyment were easily achieved.

Ríos-Rincón et al. [46] developed a home-based robot intervention where a child with spastic quadriplegia C.P. played with a Lego MindStorms "Roverbot" with a shovel at the front. They found that the participant's playfulness level increased slightly. However, the participant did not use the robot during the entire session and preferred to play with her toys (e.g. Ernie doll, walker toy, blanket, toy beaded necklace). Better results were found in another study with three more participants led by the same authors [23], which used the same robot but this time equipped with a scoop, and where the scores of the four children significantly increased during the intervention compared with baseline. Additionally, they found that participants' manipulation capacity improved.

The study conducted by Mariager et al. [48] used a mobile robot game called "TurtleBot3 Burger" to create a playful environment where the participants (children with C.P.) were instructed to hit the correct cone, which was placed in front of them. The authors found that the intervention was able to trigger positive social interactions in the participants. Finally, the feasibility study conducted by Kronreif et al. [49], which aimed to develop "PlayROB", a remote-controlled robot system designed to help children with significant physical and cognitive impairments to handle LEGO bricks, and analyse how children with multiple physical disabilities play when using it, found that most of the children enjoyed playing with the system (some of them for up to one hour) and the goal to develop an autonomous play activity for children with physical disabilities was achieved. However, a participant with intellectual impairments did not fully understand the link between using the input device and the control of the robot.

3.4.3. Influence of the Interventions in the Cognitive Skills and Engagement in Activities of CwSMI

As for the five studies aimed to measure the influence of the intervention both on cognitive skills and engagement in the activity, two were non-randomised controlled trial design [38,52], two were SCD studies [42,43], and one was a pre-experimental SCD study [50]. Three of the studies were led by Cook. The first one [38], based on the creation of a learning environment for young children with developmental delay by using a MiniMover-5 robotic arm, found that all children with an overall developmental age of 7-8 months and over, associated pressing the switch with the robotic arm's movement. None of the children appeared to enjoy passively watching the arm complete movements. However, when the arm was trained to bring an object to the child, the children would actively participate for relatively long periods. In a later study, Cook et al. [42] showed that the use of a robotic arm (CRS A465) allowed all participants (children with severe C.P.) to engage in cooperative play activity with an adult for longer than usual and displaying a very motivated behaviour. All children were able to learn how to control one switch to activate a pre-stored action, although most of them required physical and verbal prompts to use the second switch to trigger the "dig object from macaroni" action, as well as to use the third switch to trigger the "move horizontally" action of the arm. Another study by Cook et al. [43] aimed to determine the impact of the use of a robotic arm (Rhino XR-4) on the behaviour and the social and academic performance of children with spastic quadriplegia. This study reported that the robot generated tasks were more motivational and interesting than single switch tasks such as toys, appliances, or computer activities. They found that all children improved in operational competence of the robot, and the level of prompting decreased during the intervention. Teachers reported improvements in classroom attention, participation, and expressive language during the intervention. Some participants showed carryover with increased vocalisation and classroom interaction, and others also showed anticipation of the robot sessions and more attention to classroom activities.

In addition, Kronreif et al. [50] conducted a study using "PlayROB". They found that children were able to learn what kind of figures could be built with the bricks, becoming increasingly complex, placing more bricks in less time over a larger playground area, and with more accuracy and precision over time. Most of them showed significant advancement in endurance and concentration, but also in spatial perception, over a longer period. Using the robot resulted in a general improvement of self-esteem and motivation during the lectures. Participants' interest in playing with the robot did not decline during the time of the intervention. However, not all children could finally be transferred from "free playing" to "instructed playing", and teachers and therapists reported that introducing the robot within the regular therapy plan posed an extra workload for the already overloaded sessions.

Two of the included studies were conducted by Acevedo-Londoño et al. The oldest one [52] assessed the influence of the intervention on the cognitive skills, along with engagement in the activity, and physical skills, and the more recent [53] only focused on the measurement of the cognitive skills [53]. Although we classified them into different categories based on the outcomes they assessed, we report their results together as the intervention was similar in both. The first one [52] tested the effectiveness of an intervention for upper limb rehabilitation, based on the use of SpinBOT. They compared the results between a case group composed of two children, one with spastic C.P. and one with hemiparesis and hypotonia in the upper limbs, and a control group, composed of two children with hemiparesis, and reported that the robot enabled symbolic play. Participants in the case group progressively learned to operate the robot, motivating them to attend therapy sessions, in addition to developing physical and cognitive skills. These participants were able to achieve supination and pronation movements of the forearm, wrist flexion, and extension. Parents and caretakers noticed an improvement in attention and motivation. Remarkably, there was no improvement in the articular range in the participants of the control group. In a subsequent study the following year [53], the same authors collected more exhaustive data related to the cognitive skills, and reported that the participants' navigation skills and strategies improved (spatial orientation, memory, etc.), as showed by both participants requiring decreasing time and fewer control-button presses to reach the end goal because they collided less over time, presumably because their mental strategies to solve the problem were increasingly effective. The authors also reported that participants' language skills improved.

3.5. Quality Assessment of the Studies and EBP of the Interventions

According to a five-criteria study quality assessment based on an adapted version of Khan et al. [36], the quality of the 17 reviewed studies was mainly poor, and there was considerable risk of bias within studies (table 2). None of the studies were based on a representative sample selected from a relevant population, and only four reported the inclusion criteria explicitly [23,44,45,51]. Out of the four studies that compared groups (three between cases and controls, and one between different interventions), only in three [38,52,53] were both groups comparable with respect to potential confounding factors. Only three studies [23,45,46] used an appropriate statistical method, while another four performed simple statistical analysis, including descriptive results with percentages [44,50,51] and plots [43]. In addition, only two studies [41,46] assessed all their outcomes using objective criteria, and nine [23,38–40,43,50–53] assessed some (not all) of their outcomes using objective criteria.

Looking at the SCD studies, according to the guidelines presented on the "What Works Clearinghouse - Single-case design technical documentation" [35], the eight included studies reported information about the systematic manipulation of the independent variable, and involved, at least, three attempts to demonstrate an intervention effect each at a different point in time. However, only four of the eight SCD studies [23,39,40,44] included a minimum of three data points per phase, and three [23,43,44] reported information about the systematic measurement of each outcome by more than one assessor (including information about the inter-assessor agreement in each phase) on at least twenty percent of the data points in each condition. Hence, only two of the eight SCD studies [23,44] met the four design standards. Yet, only one [23] proved strong evidence of treatment, by reporting the consistency of level, trend, and variability within each phase; the immediacy of the effect, the proportion of data overlap between phases, the consistency of the data across phases; and having in account the external factors and anomalies.

In accordance with the *National Professional Development Center on Autism Spectrum Disorder* [37], none of the analysed interventions was an EBP.

[INSTERT TABLE 2 NEAR HERE]

Table 2.: Quality assessment of the studies.

Study	**1. Is the study based on a representative sample selected from a relevant population?**	**2. Are the criteria for inclusion explicit?**	**3. Are the cases and controls comparable with respect to potential confounding factors?**	**4. Was an appropriate statistical analysis used (matched or unmatched)?**	**5. Were outcomes assessed using objective criteria?**
		Mobile robots			
Adams & Encarnação (2011) [39]	✗	✗	N/A	✗	✓**
Cook et al. (2011) [40]	✗	✗	N/A	✗	✓**
Encarnação et al. (2014) [45]	✗	✓	N/A	✓	✗
Adams & Cook (2016) [41]	✗	✗	N/A	✗	✓
Encarnação et al. (2017) [51]	✗	✓	✗	✓*	✓**
Acevedo-Londono et al. (2019) [53]	✗	✗	✓	✗	✓**
Spiegel-McGill et al. (1989) [44]	✗	✓	N/A	✓*	✗
Ríos-Rincón et al. (2013) [46]	✗	✗	N/A	✓	✓
Ferm et al. (2015) [47]	✗	✗	N/A	✗	✗
Ríos-Rincón et al. (2016) [23]	✗	✓	N/A	✓	✓**
Mariager et al. (2019) [48]	✗	✗	N/A	✗	✗
Acevedo-Londono et al. (2018) [52]	✗	✗	✓	✗	✓**
		Robotic arms			
Kronreif et al. (2005) [49]	✗	✗	N/A	✗	✗
Cook et al. (1988) [38]	✗	✗	✓	✗	✓**
Cook et al. (2000) [42]	✗	✗	N/A	✗	✗
Cook et al. (2005) [43]	✗	✗	N/A	✓*	✓**
Kronreif et al. (2007) [50]	✗	✗	N/A	✓*	✓**

* Simple statistical analysis were used

** Not all outcomes were assessed objectively

4. Discussion

4.1. Summary of Evidence

Through this scoping review we were able to answer the three proposed questions: (1) What are the extent and the type of studies about interventions developed using robots for augmentative manipulation during play activities among CwSMI?; (2) Are the developed interventions influencing the cognitive skills and engagement in activities of CwSMI?, and (3) What is the quality of these studies?

In response to the first research question, we found 17 studies focused on interventions based on the use of robots for augmentative manipulation during play activities among CwSMI. Generally, the studies were characterised by low sample sizes, and in most of them only a vague description was offered of the participants. Regarding the interventions, in general, the number of sessions was low, and most of the studies provided only an ambiguous description of them. We also detected a lack of standardisation regarding how these data were reported, resulting in an inability to properly compare different studies.

Regarding the type of robots used, we found 13 different robotic systems in the included studies, essentially consisting of robotic arms or mobile robots. The latter was the type most frequently used in the interventions (12 times). Most of them were small vehicle-like robots developed with the Robotics Invention System. Only seven robotic systems were used just as manipulation assistants, not acting as game objects.

In response to the second research question, there seems to be evidence supporting that using robots for augmentative manipulation positively influences the ability to perform different goal-oriented tasks, making choices and decisions accordingly, the understanding of the cause-effect relationships and the chaining of sequences of thoughts, as well as the promotion of the engagement in the activity and the social behaviours, including the improvement of communication skills. Findings regarding the influence of the intervention with augmentative manipulator robots on cognitive skills showed that participants were able to display skills that they possessed but that may have been difficult to demonstrate in standardised tests, as well as to improve them [38,40,42,50,52,53], and provided an opportunity to incrementally develop children's abilities to use it as a tool to perform educational tasks [39,41,43]. Results also indicated that, when comparing a physical and a virtual version of robots, children performed better in visuospatial and temporal perception with the virtual version [45], and teachers were more satisfied regarding the children's academic performance when using the virtual version [51].

Results related to the influence of the intervention with augmentative manipulator robots on the engagement in the activity showed that the use of robots during play increased the participant's playfulness level [23,46,49,50] and positive social interactions [42,43,48], and that children appeared to enjoy more when they were an active part of the activity rather than when they passively watched the robot complete movements [38].

However, these results could be biased. Most of the positive results mainly came from qualitative observations by the researchers of the studies and by parents, teachers, and other professionals caring for the participating children. Although the details of the sessions were recorded in all the studies (in video, or in log-files), in the majority of the manuscripts it is not clear if the recording was analysed by more than one rater nor do they report the inter-rater agreement level of the outcomes assessed. Only six studies reported the effects of the interventions on the participants' cognitive skills based on standardised measures: Two studies [43,52] used the Goal Attainment Scaling to measure individualised goals developed for each child, one study [51] used the Green Dot Test to measure the operational competence using the access method on the SGD (i.e., accuracy and time to select target items on the SGD) and the Prompting Scale to measure the skills with the robot according to the level of prompting required, by the child. Two studies [40,53] measured the robot-related skills by using Forman's identification (six levels), and one study [41] coded the interactions between the child and the SGD to control the robot through Light's communication competence domains. Similarly, only two studies [23,46] used standardised measures to report the participants' engagement in the activities. Both used the Test of Playfulness, and one of them [23] also used the Canadian Occupational Performance Measure for the social validation of change. Additionally, one study [52] used the System Usability Scale to measure the usability of the robot. Despite all the studies using standardised measures cited the study that referred to each one, only two studies [23,46] made literal reference to the validity and reliability of the standardised measures they used.

Finally, in response to the third research question, we found that, overall, the quality of the studies focused on the impact of the use of robots on the cognitive skills and engagement outcomes of children with motor impairment during play activities was still low. None of the studies were based on a representative sample, and most of them did not report in detail the participants' inclusion criteria. In addition, the majority of the studies did not make a comparison between cases and controls, did not carry out an appropriate statistical analysis of the results, and did not assess all their outcomes using objective criteria. Furthermore, the studies generally had small sample sizes (which is quite common in this field due to the difficulty of recruiting people with the required characteristics), and those with larger sample sizes had a high variability regarding the age and functioning of the children, whereby it is complicated to use standardised protocol, as very different cognitive constructs might be addressed depending on the age (a very mentally or physically young child versus an older child) and functioning (physical and cognitive). To improve the knowledge translation of this kind of interventions to the clinical practice, future studies should be more specific about the importance of the targeted cognitive skills for the selected age group and then, measure them specifically in a developmentally appropriate way.

Nevertheless, this is a complex research field in which applying the gold standard scientific methods is challenging. First, because it is very difficult to find large and representative participant samples in such a vulnerable population. In addition, resources for research in this area are still scarce. For future research, in those cases where the application of the gold standard scientific methods is not possible, researchers may consider using SCD studies for investigating the efficacy of robot-based interventions on improving participants' play or social skills, involving repeated, systematic measurement of dependent variables before, during, and after the interventions. SCD studies are widely used in applied and clinical disciplines in psychology and education, as they can provide a strong basis for establishing causal inference. However, to reach a good quality, these studies must have precisely defined research question(s) and objective(s), considering the specifics of the independent variable tailored to the case(s), setting(s), and the desired outcome(s); and experimental control, involving replication of the intervention in the experiment [35]. In addition, if, due to the specificity of the outcomes they are difficult to be assessed through standardised measures, participants' observed behaviours may be an alternative. However, the collected data should be measured as objectively as possible, and each outcome variable must be measured systematically over time by more than one assessor, collecting and reporting inter-assessor agreement in each phase and on at least twenty percent of the data points in each condition [35].

Moreover, we also found that none of the analysed interventions was an EBP. Due to the importance of EBP to maximise the effectiveness of interventions through adherence to principles informed by empirical findings [54] it would be helpful that future studies would make efforts to develop interventions following the criteria to consider them as EBP.

4.2. Study Limitations

We used a rigorous and comprehensive search strategy to obtain 17 articles from four databases. However, this scoping review has several limitations. First, we aimed to include studies that involved robotic systems able to manipulate the physical environment. Therefore, no robotic systems that may otherwise be valid for play by CwSMI were included. Second, most of the selected studies did not clearly state their goals or hypotheses. For this reason, some objectives of the original studies may have been left out or misinterpreted. Third, most of the included studies had a small sample size and, generally, did not use standardised measures to assess the outcomes, which might induce a small study effect, restrict generalisation, and generate publication bias.

4.3. Conclusion

The results found in this scoping review support the premise that the use of robots for augmentative manipulation during play activities among CwSMI may have a positive impact on the CwSMI's cognitive skills and engagement in activities. These studies opened a way for researching the benefits of robot mediated play. Acknowledging the difficulties of carrying out formal evaluations in this environment, this study found that the quality of most of the reviewed studies was limited and in some cases poor, which may lead to a risk of bias in their results. To improve the quality of this area of study, further research using designs that provide a higher validity is needed, as well as cross-disciplinary work between robotics experts, developmental cognitive psychologists, occupational therapists and educators to develop better study designs and protocols.

Declaration of interest

The authors report no conflicts of interest.

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