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Review

Evaluating the Efficacy of Action Observation Training in Improving Upper Limb Functionality in Children with Cerebral Palsy: A Scope Review

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Abstract

This review evaluates the efficacy of Action Observation Training (AOT) in improving upper limb functionality in children with cerebral palsy (CP). Five studies were selected based on strict inclusion criteria, focusing on clinical interventions that assessed AOT's effects on upper limb motor skills in pediatric CP populations. Across these studies, significant improvements were observed in motor skills such as reach, grasp, and spontaneous use of the affected limb, underscoring AOT's potential functional benefits. Compared to traditional therapies, AOT shows promise as a supplementary intervention that leverages neuroplasticity through action observation, with unique applications in improving motor skills in children with CP. However, limitations related to sample size and variability in CP presentations highlight the need for further research, specifically aimed at standardizing AOT protocols and including a more comprehensive array of CP types to improve generalizability and clinical application. Integrating AOT into rehabilitation programs may significantly enhance the quality of life for children with CP, making it a promising addition to therapeutic strategies.

Keywords

Action observation training; cerebral palsy; upper limb functionality; neuroplasticity; mirror neuron system

1. Introduction

Action Observation Training (AOT) is an emerging rehabilitative approach that leverages the mirror neuron system to enhance motor skills through of serving and imitating actions. Cerebral palsy (CP) is a neurological condition that significantly impairs motor function and quality of life in affected children [1-3]. CP is the leading cause of motor disability in pediatric populations, with an incidence of approximately 2-3 cases per 1000 live births in developed countries [4]. Despite advancements in neonatal care, the challenges associated with motor rehabilitation in children with CP remain complex and necessitate the implementation of effective and innovative therapeutic interventions. Current rehabilitation methods for CP include physical therapy, occupational therapy, constraint-induced movement therapy (CIMT), and neurodevelopmental treatment, each focusing on improving motor control and functional independence. However, these methods may have limitations in engaging the neural networks associated with motor learning. Action Observation Training (AOT) is promising because it leverages the mirror neuron system to facilitate motor recovery through observation and imitation of actions, potentially enhancing the effects of traditional therapies and providing a novel mechanism to promote neuroplasticity. The mirror neuron system, discovered in the 1990s, has been shown to play a crucial role in motor learning and neuroplasticity [1, 5]. These neurons are activated both during the execution of an action and during the observation of the same action performed by others, suggesting that observing motor actions can facilitate the acquisition of motor skills and the reorganization of damaged neural circuits [6-10]. AOT, which has already been successfully applied in adults for post-stroke recovery [11, 12] and in patients with Parkinson's disease [13], may represent a promising strategy for the rehabilitation of children with CP as well. Despite the potential of AOT, the scientific literature on this approach in children with CP is still limited and fragmented [14, 15]. While limited, studies on AOT in children with CP indicate promising trends, such as improved upper limb functionality, enhanced spontaneous use of the affected limb, and evidence of neurophysiological changes supporting functional recovery. These studies collectively suggest that AOT may stimulate motor improvements and complement other therapeutic approaches, although findings are varied and depend on factors like AOT protocol, age, and CP severity. Recent studies have suggested that AOT could improve upper limb functionality and spontaneous use of the affected limb in children with CP [16, 17].

However, the available evidence requires further investigation to establish its clinical efficacy and optimal application methods. There is, therefore, an urgent need for well-designed and rigorous studies to evaluate the impact of AOT on key motor outcomes in children with CP. The primary objective of this manuscript is to systematically review the existing literature on the effects of AOT in the rehabilitation of children with CP. Given the current variability in study designs and outcomes, this scoping review approach was selected over a systematic review to map the breadth of available evidence on AOT in CP populations. A scoping review allows for the inclusion of diverse study types and provides a comprehensive overview of AOT's potential applications and limitations. This approach aims to identify gaps and inform future research directions by summarizing existing evidence on the functional and neurophysiological effects of AOT in CP rehabilitation, with a specific focus on upper limb functionality and the spontaneous use of the limb in daily activities. This review includes studies focused on children diagnosed with CP, specifically assessing upper limb motor impairments and those that investigate AOT's effects on motor learning and neuroplasticity. Exclusion criteria are applied to studies lacking sufficient methodological rigor or those focusing exclusively on unrelated motor interventions. This review intends to highlight specific areas where AOT might be effectively integrated within pediatric CP rehabilitation by narrowing the scope to include clinically relevant AOT interventions. By compiling and analyzing the current evidence, this review provides a comprehensive overview of AOT's effectiveness and guides future studies in optimizing this therapeutic approach for children with CP. This will ultimately contribute to the development of more effective rehabilitation strategies [12, 18-24], enhancing the quality of life for these patients and their families. By synthesizing evidence on AOT's applications in CP, this review could directly influence clinical practice, guiding clinicians in adopting AOT as an adjunct to traditional therapies. Additionally, identifying current limitations and areas needing standardization may inform policy recommendations for developing structured protocols to maximize the therapeutic potential of AOT in pediatric rehabilitation settings.

2. Methods

The present scoping review was conducted following the JBI methodology [25] for scoping reviews. The Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [26] Checklist for reporting was used.

2.1 Review Question

We formulated the following research question: "What is the efficacy of Action Observation Training (AOT) in improving upper limb functionality and spontaneous use in children with cerebral palsy?"

2.2 Eligibility Criteria

Studies were eligible for inclusion if they met the Population, Concept, and Context (PCC) criteria.

2.2.1 Population

The target population for this review includes children diagnosed with cerebral palsy (CP), focusing specifically on those with impairments in upper limb motor functionality. CP is a complex neurological disorder that commonly impacts motor function, resulting in varying degrees of disability that affect daily activities and quality of life. In this review, we included studies where participants were children with a confirmed CP diagnosis, particularly those experiencing difficulties in upper limb function, which is crucial for independence and participation in daily activities. Focusing on upper limb impairments, we aim to assess the potential impact of interventions like Action Observation Training (AOT), specifically on motor functionality improvements in this area, a critical aspect for children with CP.

2.2.2 Concept

This review examines the implementation of Action Observation Training (AOT) as a rehabilitative intervention. AOT is based on the mirror neuron system, a network of neurons activated when an individual performs an action and when they observe another performing the same action. AOT leverages this system in pediatric CP populations to facilitate motor learning and neuroplasticity through structured observation and imitation exercises. Studies were included if they focused on AOT's effect on upper limb motor skills, evaluating outcomes related to motor learning improvements and the potential for neuroplastic changes. This intervention has been chosen due to its potential to enhance motor function without invasive methods, aligning well with the rehabilitation needs of children with CP.

2.2.3 Context

Studies must be conducted in clinical or rehabilitative settings, where structured AOT protocols were administered to children with CP. The aim was to evaluate AOT's effectiveness in improving upper limb functionality and promoting the spontaneous use of the affected limb in daily tasks. We focused on studies published within the last ten years in peer-reviewed journals to ensure that the review reflects current practices and the latest advancements in pediatric CP rehabilitation. This temporal criterion is essential to capture recent improvements in AOT methodologies, intervention delivery, and outcome measurement, offering a more accurate understanding of AOT's clinical potential for children with upper limb impairments due to CP.

2.3 Exclusion Criteria

Studies that did not meet the specific PCC criteria were excluded.

2.4 Search Strategy

An initial limited search of MEDLINE was performed through the PubMed interface to identify articles on the topic, and then the index terms used to describe the articles were used to develop a comprehensive search strategy for MEDLINE. The search strategy, which included all identified keywords and index terms, was adapted for use in Cochrane Central, Scopus, PEDro. In addition, grey literature (e.g., Google Scholar, direct contacts with experts in the field) and reference lists of all relevant studies were also searched. Searches were conducted on 23 April 2024 with no date limitation. The search strategy employed a combination of keywords and MeSH terms to capture relevant studies on Action Observation Training (AOT) in children with cerebral palsy (CP). Key terms included 'cerebral palsy,' 'Action Observation Training,' 'mirror neuron therapy,' 'upper limb functionality,' and 'rehabilitation.' Boolean operators (AND, OR) were used to structure the search strings, and filters were applied to limit results to peer-reviewed articles published in the last ten years. This structured approach was applied across MEDLINE, Cochrane Central, Scopus, and PEDro databases to capture studies meeting our criteria comprehensively. Grey literature sources, including conference proceedings and unpublished reports, were assessed for relevance and quality based on author expertise, sample size, and study design criteria. Only sources with sufficient methodological rigor and relevance to the review's objectives were included to ensure the reliability and applicability of findings from grey literature.

("cerebral palsy" OR "CP" OR "spastic diplegia" OR "hemiplegic cerebral palsy" OR "quadriplegic cerebral palsy") AND ("action observation training" OR "AOT" OR "action observation therapy" OR "mirror neuron therapy" OR "motor learning through observation") AND ("upper limb function" OR "upper extremity function" OR "hand function" OR "arm function" OR "motor function" OR "motor skills" OR "spontaneous use") AND ("rehabilitation" OR "therapy" OR "treatment" OR "intervention") AND ("randomized controlled trial" OR "RCT" OR "clinical trial" OR "systematic review").

2.5 Study Selection

The process described involves a systematic approach to selecting studies for a scoping review. Initially, search results were collected and refined using Zotero, with duplicates removed. The screening involved two levels: title and abstract review, followed by full-text assessment, conducted independently by two authors, with discrepancies resolved by a third. The selection adhered to the PRISMA 2020 guidelines, ensuring transparency and reliability. This rigorous methodology aimed to identify relevant articles that directly address the research question, maintaining a comprehensive and systematic approach in the review process. Studies included in this review were selected through a rigorous, systematic search process across multiple databases, adhering to established guidelines for scoping reviews. Disagreements between reviewers during study selection were resolved through a structured consensus process. When conflicts arose, both reviewers met to discuss their assessments, referring to the eligibility criteria and quality assessment guidelines. If consensus was not reached, a third reviewer facilitated the final decision, ensuring that the selection process adhered to the PRISMA guidelines for systematic transparency. The search targeted peer-reviewed studies on Action Observation Training (AOT) and its effects on upper limb function in children with cerebral palsy (CP). Each study was evaluated for methodological rigor using the PEDro scale, which assesses the quality of randomized controlled trials (RCTs) and other intervention studies based on random allocation, baseline comparability, and blinding criteria.

Following the methodological assessment, we conducted a thorough comparative analysis of primary outcome measures across studies, focusing on tools like the Assisting Hand Assessment (AHA) and the Melbourne Assessment of Unilateral Upper Limb Function (MUUL). These measures were chosen due to their validated use in assessing upper limb functionality and spontaneous hand use in children with motor impairments. We identified consistent trends in AOT efficacy across various study designs and intervention protocols by analyzing these outcomes.

Additionally, cross-referencing allowed for the identification of shared findings and unique insights across studies despite differences in participant characteristics and intervention specifics. This approach enabled us to build a comprehensive synthesis of AOT's potential in enhancing motor function and engaging neuroplasticity within the pediatric CP population, providing a balanced overview of AOT's effectiveness and limitations. Such synthesis enhances the robustness of our findings by integrating data across a diverse yet methodologically sound body of literature.

2.6 Data Extraction and Data Synthesis

Data extraction for the scoping review was done using a form based on the JBI tool, capturing crucial details like authorship, publication country and year, study design, patient characteristics, outcomes, interventions, procedures, and other relevant data. Descriptive analyses of this data were conducted, with results presented numerically to show study distribution. The review process was mapped for transparency, and data were summarized in tables for easy comparison and understanding of the studies' key aspects and findings. Data synthesis was performed using a descriptive-analytical approach, where findings from each study were systematically categorized and tabulated to identify common themes and trends. Descriptive statistics, such as frequency counts and ranges, were used to summarize participant characteristics, intervention types, and outcomes. Key conclusions were drawn by comparing the primary outcome measures across studies, focusing on consistency in findings related to improvements in upper limb functionality. This approach provided a clear overview of AOT’s potential effects on CP rehabilitation.

3. Results

As presented in the PRISMA 2020 flow diagram (Figure 1), 158 records identified by the initial literature searches, 153 were excluded and 5 articles were included (Table 1). The quality of the studies was assessed with al PEDro scale (Table 2).

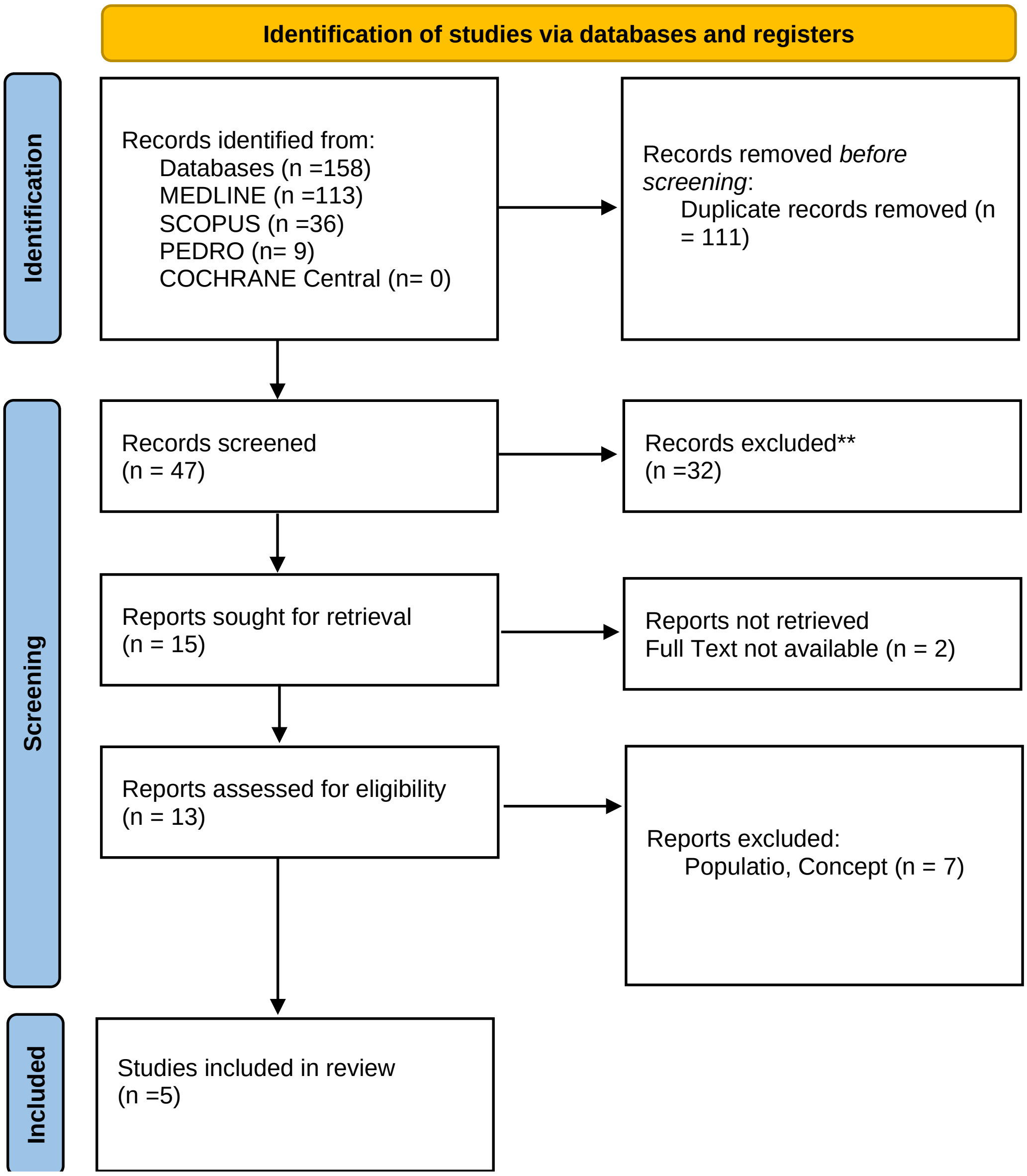

Figure 1 Preferred reporting items for systematic reviews and meta-analyses 2020 (PRISMA) flow-diagram.

Table 1 Main characteristics of included studies.

Author and Year	Objective	Population	Intervention	Outcome Measures	Results
Sgandurr a et al., 2013 [17]	Examine the effects of AOT and evaluate its efficacy in improving upper limb functionality in children with unilateral CP.	Inclusion criteria: Aged 5-15 years; spastic hemiplegic CP; Ashworth scale ≤ 2; HFCS between 4 and 8; normal cognitive level; no sensory or attentional deficits; no seizures; children living near one of the two centers; available parents. Exclusion criteria: orthopedic surgery/injectio n of botulinum toxin within three months prior to the study. n = 24 children randomized.	Experimental group (n = 12): AOT with video observation for 3 minutes, followed by execution of the same actions for 3 minutes. Each video sequence was repeated twice. Daily observation and imitation of 3 actions of increasing complexity for 60 minutes over 15 days. Control group (n = 12): Observation of video games and asked to perform the same actions in the same order as the experimental group.	Baseline, 1 week, 8 weeks, and 24 weeks post-treatment. Primary outcome: Spontaneous use of the affected hand during a semi-structured play session (AHA). Secondary outcomes: Upper limb functionality and movement quality (MUUL); bimanual activity skills in daily life (ABILHAND-Kids).	AHA: The experimental group improved compared to the control group at T1, T2, and T3. Significant improvements were made in the experimental group at different endpoints. MUUL, ABILHAND-Kids: No statistically significant differences between groups at any endpoint.
Buccino et al., 2012 [27]	Assess whether AOT can improve upper limb motor functions in children with CP.	Inclusion criteria: Confirmed CP by neuroimaging; IQ > 70; aged 6-11 years; no severe visual or auditory deficits; no antiepileptic treatment. n = 15 children randomized.	Experimental group (n = 8): AOT with video observation of upper limb actions, consisting of 3/4 sub-activities, each lasting 3 minutes. Execution of actions for 2 minutes. 15-day treatment. Control group (n = 7): Observation of the same number of videos of the same duration but without motor content. Execution of the same actions as the experimental group. Both groups continued with conventional rehabilitation.	Primary outcome: The Melbourne Assessment Scale measured upper limb motor function quality. The patient was assessed twice (T1 and T2) at baseline and within 2 days post-treatment (T3).	Melbourne Assessment Scale: Improvement s in scores over time, with significant differences between T3 and T2, and between T2 and T1. Improvement s between T1 and T3, and between T2 and T3 was observed only in the experimental group. Functional score increases in the experimental group.

Simon-Martinez et al., 2020 [28]	Investigate the added value of AOT to CIMT in improving sensorimotor function of the upper limb in children with unilateral CP. Explore the influence of behavioral and neurological factors on treatment response.	Inclusion criteria: Unilateral CP; aged 6-12 years; sufficient cooperation to complete activities; HFCS ≥ 4. Exclusion criteria: Upper limb surgery in the last 2 years or botulinum toxin injections 6 months prior to recruitment. n = 44 children randomized.	Experimental group (n = 22): CIMT + AOT + group activities. 9-day treatment, 6 hours per day. AOT with video observation of 3 sub-activities, each for 3 minutes, followed by execution for 3 minutes. Control group (n = 22): CIMT + placebo + group activities. Observation of video games and execution of the same actions as the experimental group.	Primary outcome: Spontaneous use of the affected hand during bimanual activities (AHA). Secondary outcomes: Muscle tone (Modified Ashworth Scale), strength (MRC), grip strength (dynamometer), movement quality (MA2), movement speed (JTHFT), manual dexterity (Tyneside Pegboard Test), ABILHAND-Kids, and CHEQ. Evaluation of influencing factors.	No differences between groups in outcomes. Over time: improvement s post-intervention, maintained at follow-up in AHA, MRC, grip, JTHFT, manual dexterity. Improvement s at follow-up in MA2, but only in range of motion. A low initial AHA score and a high number of mirror movements indicate greater benefits obtainable from AOT.
Buccino et al., 2018 [1]	Evaluate if AOT can improve upper limb functions in children with CP aged 5-11 years. Assess if AOT can induce neuronal changes.	Inclusion criteria: Confirmed CP by neuroimaging; MACS score ≤ 4; IQ > 70; aged 5-11 years; no major visual and/or auditory deficits; no antiepileptic treatment. n = 18 children randomized.	Experimental group (n = 11): AOT with video observation of 3/4 sub-activities, each for 3 minutes. Execution of actions for 2 minutes + conventional rehabilitation. 15 sessions of 30 minutes each. Control group (n = 7): Same duration and treatment mode, but with non-motor content videos + conventional rehabilitation. 12 children underwent MRI.	Primary outcomes: Quality of upper limb motor functions (MUUL), spontaneous use of the affected hand during bimanual activities (AHA). Evaluation of neuronal activation and reorganization post-treatment (MRI).	MUUL, AHA: Significant improvement s only in the experimental group. In the experimental group, improvement s increased at T3. MRI: At T2, the experimental group showed increased activations in frontal and parietal areas.

Quadrelli et al., 2019 [29]	Verify if the desynchronization of the µ rhythm in EEG and increased brain area activation can be correlated with AOT's effects on upper limb functions in children with CP.	Inclusion criteria: Confirmed CP by neuroimaging; aged 4-14 years; IQ > 70; MACS ≤ 4; no severe attentional, visual, and/or auditory deficits; available parents. Exclusion criteria: Orthopedic surgery and/or botulinum toxin injections within the last year; antiepileptic treatment. n = 8 children randomized.	AOT + VOT group (n = 4): AOT (18 minutes, 3 days per week for 6 weeks. 15 exercises observed and executed for 2 minutes) followed by video observation training (VOT) (observing video games followed by execution of the same actions as AOT). VOT + AOT group (n = 4): AOT followed VOT. Same treatment mode in both groups. EEG recordings before and after AOT in both groups.	Primary outcomes: Use of the affected hand during bimanual activities (AHA); quality of upper limb motor functions (MUUL). Assessments at 6 weeks and 1 day pre-treatment (T0, T1), at the end of the first 6-week treatment period (T2), and 1 day and 3 months post-treatment (T3, T4). EEG before and after AOT.	AHA: Improvements before and after AOT. No difference before and after VOT. Significant AHA improvement s only after AOT. MUUL: Significant improvements for the affected limb before and after AOT. No difference before and after VOT. EEG: Greater sensorimotor activation after AOT compared to before AOT.

Legend: AHA: Assisting Hand Assessment, AOT: Action Observation Training, ABILHAND-Kids: ABILHAND-Kids questionnaire, CIMT: Constraint-Induced Movement Therapy, CP: Cerebral Palsy, EEG: Electroencephalogram, HFCS: House Functional Classification System, JTHFT: Jebsen-Taylor Hand Function Test, MA2: Melbourne Assessment 2, MACS: Manual Ability Classification System, MRI: Magnetic Resonance Imaging, MUUL: Melbourne Assessment of Unilateral Upper Limb Function, MRC: Medical Research Council scale for muscle strength, VOT: Video Observation Training

Table 2 PEDro Scale.

Study	**Total Score**
Sgandurra et al., 2013 [17]	8
Buccino et al., 2012 [27]	8
Simon-Martinez et al., 2020 [28]	9
Buccino et al., 2018 [1]	8
Quadrelli et al., 2019 [29]	8

3.1 Motor Function Improvement (MUUL and AHA Scores)

- Overall Score Improvements:
  - MUUL: The improvements in the Melbourne Assessment of Unilateral Upper Limb Function (MUUL) scores were significantly greater in the experimental group (those undergoing Action Observation Training, AOT) compared to the control group. These improvements were sustained over time and further enhanced at the third assessment point (T3).
  - AHA: Similarly, the Assisting Hand Assessment (AHA) scores showed substantial improvements in the experimental group compared to the control group. The improvements were not only maintained but also increased at T3.
- Post-hoc Analysis:
  - MUUL:
    - At the second assessment (T2), the MUUL scores in the experimental group showed significant improvement compared to the baseline (T1) ($p < 0.001$). No significant differences were observed in the control group during the same period.
    - Further analysis indicated that the improvements from T2 to T3 were also significant ($p < 0.001$) in the experimental group, demonstrating continued progress post-intervention.
  - AHA:
    - The AHA scores at T2 were significantly different from T1 in the experimental group ($p < 0.001$), indicating a marked improvement in the spontaneous use of the affected hand.
    - Improvements continued from T2 to T3 ($p < 0.001$) in the experimental group, showing that the positive effects of AOT were sustained and even enhanced over time.
  - Comparative Analysis:
    - Comparing the post-intervention scores, the experimental group consistently outperformed the control group in MUUL and AHA assessments at all time points (T1, T2, and T3).

3.2 MRI Findings

- Pre-treatment Comparisons:
  - Initial MRI scans showed no significant differences in brain activation between the experimental and control groups before the treatment commenced.
- Post-treatment (T2):
  - After completing the treatment, MRI scans revealed increased activation in specific brain areas within the experimental group, particularly in the frontal and parietal regions, which are known to be involved in hand-object interaction tasks ($p < 0.001$).
  - Detailed MRI analysis indicated differential activation patterns in the left premotor cortex, right premotor cortex, left supramarginal gyrus, and subtle activations in the left superior temporal gyrus. These regions are associated with motor planning and execution, supporting the hypothesis that AOT can enhance neural engagement and reorganization in children with CP.

3.3 EEG Analysis

- AHA Scores:
  - EEG results showed a significant improvement in AHA scores post-AOT ($p = 0.01$), while no significant changes were observed post-VOT (Video Observation Training).
  - The direct comparison of post-AOT and post-VOT scores demonstrated significant improvements ($p < 0.05$), indicating the effectiveness of AOT in enhancing the spontaneous use of the affected hand.
  - No significant differences were noted in other comparisons, suggesting the specific impact of AOT on motor function improvement.
- MUUL Scores:
  - For the more affected limb, the MUUL scores revealed significant improvements post-AOT ($p < 0.01$), while no significant changes were observed post-VOT ($p = 0.74$).
  - The comparison of post-AOT and post-VOT MUUL scores showed significant differences ($p < 0.05$), reinforcing the positive effects of AOT on upper limb functionality.
- Sensorimotor Activation:
  - EEG recordings indicated that sensorimotor activation, particularly in areas corresponding to electrodes C3/C4, was significantly greater after AOT compared to before the intervention. This increased activation correlated with the functional improvements of the MUUL scores for the more affected limb.
  - Enhanced sensorimotor activation suggests that AOT can modulate cortical activity, thereby contributing to motor function recovery in children with CP.

The results collectively indicate that AOT significantly enhances upper limb functionality and spontaneous use in children with cerebral palsy. The improvements in MUUL and AHA scores were more pronounced in the experimental group undergoing AOT compared to the control group, and these gains were sustained and even increased over time. MRI findings support the notion that AOT facilitates neural reorganization in motor- related brain areas, while EEG data confirm enhanced sensorimotor activation correlating with functional improvements.

4. Discussion

The studies analyzed reveal several differences in participant characteristics, treatment modalities, and outcome measures. Despite these variations, a common goal across all studies was to evaluate the efficacy of Action Observation Training (AOT) in improving upper limb functionality in children with cerebral palsy (CP). This discussion synthesizes the findings, highlights the limitations, and discusses the clinical implications of AOT based on the reviewed studies. The studies reviewed varied in their inclusion criteria, particularly concerning the types of cerebral palsy and the age ranges of the participants.

Sgandurra et al. (2013) [17] included children with spastic hemiplegic CP aged 5 to 15 years, all possessing minimal manual abilities, such as the capacity to grasp and weakly hold objects. This criterion was crucial for ensuring participants engaged meaningfully in the AOT activities. Buccino et al. (2012) [27] included children with different forms of CP, including hemiplegia and tetraplegia, indicating clinical diversity among participants. Simon-Martinez et al. (2020) [28] focused exclusively on children with hemiplegic CP aged 6 to 12 years, while Buccino et al. (2018) [1] included both hemiplegic and tetraplegic children, highlighting the heterogeneity in clinical presentations. Across the studies, standard exclusion criteria included insufficient IQ for the required tasks, sensory or attentional deficits, ongoing antiepileptic treatment, and recent upper limb surgery or botulinum toxin treatments. These criteria ensured that the children could actively participate and benefit from the intervention. However, they also limited the generalizability of the findings to a broader population of children with CP. The intervention protocols varied among the studies. Sgandurra et al. (2013) [17] designed a comprehensive AOT program involving 15 daily life activities, each broken down into three actions of increasing complexity. This structured approach aimed to challenge the children and facilitate motor learning progressively. The control group observed video games instead of action-based videos, ensuring a clear distinction between the experimental and control conditions. Buccino et al. (2012) [27] applied a similar AOT protocol but allowed participants to continue conventional rehabilitation, which may have influenced the outcomes. Simon-Martinez et al. (2020) [28] employed a more intensive AOT regimen, incorporating Constraint-Induced Movement Therapy (CIMT) and group activities. This combination aimed to assess the added value of AOT to CIMT, a well- established rehabilitative approach. In contrast, Buccino et al. (2018) [1] opted for shorter, 30-minute sessions, reducing the observation and imitation times. This study also included functional MRI assessments to explore neuronal activation changes post-AOT. Quadrelli et al. (2019) [29] conducted a crossover study where participants received both AOT and a placebo treatment in different sequences. This design provided insights into the temporal effects of AOT but differed in intensity and frequency compared to other studies, with shorter sessions and a less frequent schedule. Despite the differences in intervention protocols, all studies aimed to measure the efficacy of AOT in improving upper limb functionality. The primary outcomes included the Assisting Hand Assessment (AHA) for spontaneous use of the affected limb and the Melbourne Assessment of Unilateral Upper Limb Function (MUUL) for movement quality. These standardized measures allowed for cross-study comparisons despite variations in secondary outcomes and additional assessments, such as parent-reported questionnaires on daily activities and muscle strength evaluations. Follow-up periods varied, with some studies assessing short-term effects and others examining long-term outcomes up to six months post-intervention.

Sgandurra et al. and Simon-Martinez et al. 2020 [28] included follow-ups at six months, providing insights into the sustained benefits of AOT, while Buccino et al. (2018) [1] and Quadrelli et al. (2019) [29] had shorter follow-up periods. Buccino et al. (2012) [27] only assessed short-term outcomes, limiting the understanding of AOT's long-term efficacy. The overall findings from the studies indicate significant improvements in upper limb functionality in the experimental groups receiving AOT compared to control groups. This suggests that AOT effectively enhances motor skills in children with CP. The improvements in AHA and MUUL scores were more pronounced and sustained in the experimental groups, highlighting the potential of AOT to facilitate meaningful functional gains. MRI and EEG assessments in studies by Buccino et al. (2018) [1] and Quadrelli et al. (2019) [29] demonstrated increased neuronal activation and reorganization in motor-related brain areas post-AOT. These neurophysiological changes correlate with the observed functional improvements, supporting the hypothesis that AOT engages neural mechanisms involved in action execution and observation. Our findings align with previous studies demonstrating improvements in upper limb functionality in children with cerebral palsy (CP) following Action Observation Training (AOT). Notably, this study's enhancements in motor function and spontaneous use of the affected limb corroborate prior research emphasizing AOT's potential in pediatric populations. However, our study uniquely contributes by providing evidence in children with specific inclusion criteria, further expanding the knowledge of AOT's applicability within a clinical pediatric setting for CP.

For instance, Beani et al. (2023) [30] conducted a randomized controlled trial investigating the effectiveness of a home-based AOT program, Tele-UPCAT, in children with unilateral CP. The study reported significant improvements in upper limb skills, highlighting the feasibility and efficacy of AOT delivered remotely. Similarly, Buccino et al. (2018) [1] explored the impact of AOT on upper limb motor functions in children with CP through a combined clinical and brain imaging study. The results indicated notable enhancements in motor performance, supported by neuroimaging evidence of cortical reorganization, underscoring AOT's role in promoting neuroplasticity. Furthermore, a systematic review by Alamer et al. (2020) [31] assessed the effectiveness of AOT on upper limb motor function in children with CP. The review concluded that AOT is a promising intervention for upper limb rehabilitation, with multiple studies demonstrating significant functional improvements. While only five studies met the inclusion criteria for this review, limiting the sample size and generalizability of findings, these studies provide valuable preliminary insights into the potential of AOT for improving upper limb function in children with cerebral palsy (CP). The differences in inclusion criteria and AOT intervention protocols across these studies highlight the need for future research with standardized methodologies. Specifically, we recommend that future studies adopt larger, multicenter designs and standardized AOT protocols to enhance consistency and enable broader application of results. Moreover, exploring optimized AOT protocols—such as varying the frequency, duration, and types of observed actions—could further clarify AOT's therapeutic potential and its specific impact on different CP presentations. Such improvements in study design and protocol consistency will strengthen the evidence base for AOT's clinical applications and allow for more targeted recommendations in CP rehabilitation.

4.1 Limitations

Despite these positive findings, several limitations must be acknowledged. The small sample sizes in most studies limit the generalizability of the results. Additionally, the inability to blind therapists due to the nature of the intervention introduces potential bias. Variations in CP types and AOT administration methods across studies make it challenging to draw definitive conclusions about the optimal implementation of AOT. Furthermore, the exclusion of children with severe cognitive, sensory, or attentional deficits and those unable to use their upper limbs actively restricts the applicability of the findings to a broader CP population. The differences in follow-up durations also limit the ability to compare long-term outcomes consistently. The primary limitations identified include the limited sample size, heterogeneity in intervention protocols, and potential selection bias due to inclusion criteria. To address these, we propose that future studies adopt a multicenter approach, enabling larger sample sizes and protocol standardization across sites. Moreover, introducing longitudinal follow-ups could help confirm the durability of AOT benefits. These measures will improve the generalizability of findings and support the standardization of AOT applications for diverse clinical populations.

4.2 Clinical Implications

Despite these limitations, the evidence supports the integration of AOT into rehabilitation programs for children with CP. AOT can be a valuable adjunct to conventional therapy, enhancing upper limb functionality and spontaneous use in daily activities. The ease of application, lack of side effects, and potential for remote administration make AOT a practical and flexible option for clinicians. Tailoring AOT to individual capabilities and repeating treatments periodically could sustain and enhance motor improvements, ultimately improving the quality of life for children with CP and their families. AOT offers a promising rehabilitative approach that can be integrated into existing therapy protocols. Clinicians should consider individual needs and functional levels to maximize their therapeutic potential and ensure comprehensive motor skill development in children with CP. Further research with larger, more diverse samples and standardized protocols is needed to validate these findings and optimize AOT for broader clinical applications. Despite the small sample size, this study provides preliminary evidence that AOT can improve functional outcomes in children with CP, particularly in enhancing the spontaneous use of the affected limb. While these findings are not yet generalizable to a larger population, the data suggest that AOT may help foster independence in children with CP when integrated into their therapeutic regimens. Further research is needed to confirm these outcomes across a broader demographic to maximize AOT's impact on pediatric rehabilitation.

5. Conclusions

Action Observation Training (AOT) has demonstrated significant potential in improving upper limb functionality in children with cerebral palsy. The studies reviewed show that AOT can enhance motor skills, engage neural mechanisms associated with action observation and execution, and sustain functional gains over time. Despite limitations such as small sample sizes and variability in intervention protocols, the evidence supports incorporating AOT into conventional rehabilitation programs. Future research should focus on larger, more diverse samples and standardized AOT protocols to validate its efficacy and optimize clinical application. This review contributes to the existing literature by highlighting AOT as a replicable and flexible adjunct to traditional CP therapy. While previous research has explored AOT's efficacy in adult rehabilitation and post-stroke recovery, our study is among the few that document AOT's effectiveness in enhancing upper limb functionality in children with CP. It reinforces the non-invasive approach, supporting neuroplasticity and motor skill development, and underscores its potential integration into standardized rehabilitation protocols.

Author Contributions

Danilo Donati, Roberto Tedeschi: Conceptualization, Methodology, Software, Data curation, Writing-Original draft preparation. **Federica Giorgi**: Supervision. **Andrea Bernetti, Giacomo Farì**: Visualization, Investigation, Writing-Reviewing and Editing.

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Competing Interests

There are no conflicting relationships or activities.

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