



## Effectiveness of interactive computer play on balance and postural control for children with cerebral palsy: A systematic review

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### ABSTRACT

**Background:** Interactive computer play (ICP) becomes popular in rehabilitation for children with cerebral palsy (CP). With the nature of ICP, it could be an effective intervention specifically to improve balance and postural control for children with CP. The present paper aimed to review the effectiveness of ICP on postural control and balance for children with CP.

**Methods:** Electronic databases including Medline, AMED, EBSCOhost, PsycINFO, Embase, the Cochrane Library and the DARE were searched up to September 2018. Studies were included if (1) participants were aged under 18 and had CP, (2) ICP intervention was performed, (3) an explicit objective was postural control and balance of the participants, and (4) results were fully published in English-language peer-reviewed journals. Characteristics of study participants, ICP protocols and study results were extracted. Level of evidence of each study was graded using the guidelines from the American Academy of Cerebral Palsy and Developmental Medicine. Methodological quality was graded using the Physiotherapy Evidence Database (PEDro) scale. Effect sizes were calculated on available data.

**Results:** Twenty studies were included, with nine of level I or II evidence. Most studies had fair methodological rigor. Huge variations in the study designs and protocols of ICP were found among the studies.

**Conclusions:** ICP seemed to be more effective than conventional therapy in improving postural control and balance, with medium to large effect sizes for children with mild to moderate severity of CP. Future studies of high methodological rigour are required to verify the role of on-site guidance of the children during ICP and the effect on children with more severe CP.

Although cerebral palsy (CP) is a non-progressive lesion of the developing central nervous system, it affects the control of movements and posture in children [1]. Children with CP are usually classified using the Gross Motor Function Classification System (GMFCS) into five levels according to age-specific gross motor function [2]. Children of levels I and II can generally walk without aids while children of level III can walk with aids for short distances but use wheeled mobility in community settings. Children of level IV have limited ability in standing, stepping and transfer between positions. Children of level V are completely dependent on others for transportation and lack anti-gravity postural control [2]. Regardless of their GMFCS levels, children with CP have been shown to demonstrate problems in their postural control in sitting and standing [3,4]. In sitting, the main deficit in postural control is lack of ability to recruit direction-specific muscles for children of GMFCS levels IV and V or inability to fine-tune the degree of muscle contraction to specific situations for children of levels I and II

[3]. Excessive contraction of antagonists is a common compensatory strategy of children of all levels [3]. In standing, children of GMFCS levels I to II use more proximal muscles in the hips to maintain their balance, unlike typically developing children, who use more distal muscles [4]. As in sitting, co-contraction of muscles around the joint is a common compensation for inadequate postural control in standing. These ineffective strategies to compensate for their imbalance in sitting and standing cause early fatigue and affect the children's daily function, such as desk work at school, transfer between positions and ambulation [5].

In the last decade, with the advances in computer technology, interactive computer play (ICP) has become a popular means of rehabilitation for people with motor impairments, including children with CP [6–16]. During ICP, a child interacts and plays with virtual objects in a computer-generated environment, through the use of a computer console or platform and specialised software, allowing the

**Abbreviations:** CP, cerebral palsy; GMFCS, Gross Motor Functional Classification Scale; ICP, interactive computer play; MSSRD, multiple single-subject research design; PEDro, Physiotherapy Evidence Database; RCT, randomized controlled trial

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child to control the games through their body movements [8]. The computer games are designed to be fun and enjoyable, so that the child will repeat the required body movements numerous times to get a high score in the game without losing interest. These numerous repetitions (essentially mass practice) and feedback via the game scores (knowledge of performance and results) are important in motor learning and enhancing neuroplasticity [17]. Hence, ICP may be a feasible way to improve balance and postural control in children with CP, being one of the rare modalities in which children have to actively control and move their trunk in a task-specific context to score in the games.

To date, 11 systematic reviews have been published to investigate the effectiveness of ICP in rehabilitation compared with the conventional therapies [6–16]. These reviews vary greatly in their inclusion of studies and, as a result, in their conclusions regarding this intervention. All except three [6,9,16] included studies on population groups other than CP. All except three [11,12,16] included studies on children only. All of these reviews examined the effectiveness of ICP on different aspects of sensori-motor function and motivation of the participants. None of the reviews focused on the effectiveness of ICP on balance and postural control for children with CP.

The present systematic review aimed to examine research evidence of the effectiveness of ICP in improving postural control and balance when compared with conventional therapy for children with CP. With the rapidly increasing number of publications in this area in the last decade [11], the time was considered ripe to report on the efficacy of ICP for this population group so that clinicians could make an informed decision about this intervention for their clients.

## 1. Method

### 1.1. Inclusion and exclusion criteria

Studies were included if (1) participants were aged 18 years or less, (2) participants had CP, (3) participants received ICP as a sole intervention or in addition to conventional therapy, (4) it was explicitly stated that to examine the effect of ICP on balance and postural control of the participants was one of the study objectives, and (5) the results were published in full in English-language peer-reviewed journals. Relevant data from studies consisting of a mixed group of participants with CP and other neurological disorders were only included if the results for participants with CP could be separated. The same principle was applied for those studies consisting of both children and adult participants, i.e. data on the children were only included if able to be separated. Studies using ICP merely as a means to facilitate another intervention, e.g. use of virtual reality during treadmill training, were excluded.

### 1.2. Search strategy

A selection of databases including Medline (via Ovid), AMED, EBSCOhost (CINAHL complete, Academic Search Premier, SPORTDiscus and Medline 1965+), PsycINFO, EMBASE, the Cochrane Library and the DARE were searched from the earliest date available in each database to November 1, 2018. These databases were chosen to cover a variety of disciplines and mixed fields of biomedical clinical practice and health. The terms ‘video games’, ‘computer games’, ‘commercial games’, ‘serious games’, ‘virtual reality’, ‘augmented reality’, ‘Play Stations’, ‘X-box’, ‘Nintendo’, ‘Wii’ and ‘Kinect’, ‘cerebral palsy’ and ‘postural control’, ‘trunk control’, ‘posture’ and ‘balance’ were searched as a combination of subject headings and free text. Examples of search strategies are provided as a supplementary material of this manuscript. Appropriate Boolean symbols and linking terms were used. The results were further limited to studies involving children aged 18 years or less. The reference lists of key papers and known systematic reviews were also searched for citation tracking and by hand to ensure that relevant articles were not missed. The titles and abstracts

of articles identified in the initial search were firstly screened against inclusion and exclusion criteria. No authors of included and excluded studies were approached to retract missing data. Data on study characteristics, protocols of ICP and results was extracted. Effect size would be calculated if adequate study data was available.

### 1.3. Levels of evidence and quality assessment

The level of evidence of each included study was graded according to the guidelines from the American Academy of Cerebral Palsy and Developmental Medicine Treatment Outcome Committee for the development of systematic reviews [18]. This classification of levels of evidence is a modification of Sackett’s hierarchy of levels of evidence [19], which also grades single-subject research designs. Details of the classification are also provided as a supplementary material of this manuscript [18].

The Physiotherapy Evidence Database (PEDro) scale was also used to assess the methodological rigour of the included studies [20]. The PEDro scale examines 11 aspects of methodological rigour: (1) eligibility criteria specified; (2) randomisation of participants; (3) concealed allocation of participants; (4) comparability of subject groups at baseline; (5) blinding of participants; (6) blinding of therapists; (7) blinding of assessors; (8) more than 85% follow-up of participants in at least one of the key outcomes; (9) ‘intention to treat’ analysis; (10) between-group statistical analysis of at least one of the key outcomes; and (11) point estimate of at least one of the key outcomes. According to the PEDro guidelines, a positive answer to criteria (2) to (11) will yield one point, resulting in a PEDro score from 0 to 10 [20]. Studies were arbitrarily classified with ‘poor’ methodological quality if the PEDro score was  $\leq 3$ , ‘fair’ if the score was between 4 and 5 and ‘high’ if the score was  $\geq 6$  as suggested in the literature (<https://www.strokengine.ca/en/glossary/pedro-score/>).

## 2. Results

Of the 1640 studies identified in the electronic searches and 4 potential studies identified in the manual search, 40 met the inclusion criteria (Fig. 1). Full text analysis of these 40 studies led to the exclusion of another 16 articles (see details in Fig. 1). Three studies from the same research team had very similar intervention protocols [21–23]. It was not possible to determine if the data were from the same study and hence all three studies were treated as one entity [23]. Similar decision was made on another two studies [24,25] and they were treated as one entity [24]. Twenty-one empirical studies were therefore included for the present review.

The 21 studies included 15 group studies [23,24,26–38], four multiple single-subject research designs (MSSRDs) [39–42] and two case reports [43,44]. Ten studies obtained level I or II evidence through randomized controlled trials (RCTs) [23,24,26,29,33,35,27–38] or MSSRDs with more than three participants [40] (Table 1). Four studies [30,32,34,39] were of level III evidence through non-RCT or non-randomized, non-concurrent controlled MSSRD. Three level IV evidence studies [27,28,31] were before and after cohort studies without controls. Two MSSRDs with less than three participants [41,42] and the two case reports [43,44] were of level IV and V evidence respectively. The mean PEDro score of the included studies was 4.8 (SD 1.5) (Table 2). The majority of the studies had fair study quality (high quality  $n = 5$ , fair  $n = 13$  and poor  $n = 3$ ).

Table 1 also summarizes the characteristics of the study participants. The study participants were mainly of GMFCS levels I and II. Only nine studies involved participants of more severe CP [26,28,29,32,34,35,37,38,41,44]. The majority of the studies assessed the participants at baseline and completion of the intervention. Seven studies [23,30–32,39,40,44] conducted follow-up assessments, varying from 1 to 4 months post-intervention. Table 3 summarizes the ICP protocols and results of the included studies. Nine studies used ICP as

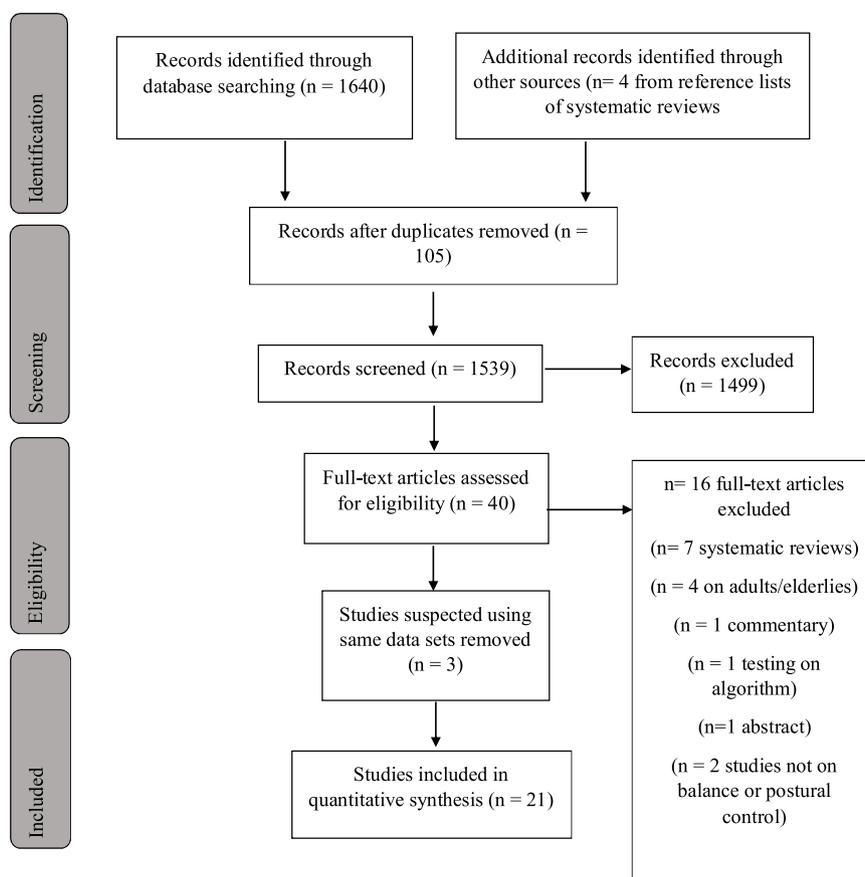


Fig. 1. Flowchart of included studies.

an additional intervention to the conventional therapy and nine studies did not specify this condition. The intervention participants of three studies [23,26,40] stopped their conventional therapy during the clinical trial. The dosage of ICP varied from 25 to 90 min per session, from 1 to 5 sessions per day to 1 to 7 sessions per week and from 5 consecutive days to 20 weeks in duration. Both kinetic measures of postural sway [23,29,30,33,43,44] and clinical balance tests [24,26–29,31,32,34–42], such as timed up-and-go test, Pediatric Reach Test and Pediatric Balance Scale, were used to measure the postural control and balance of the participants. ICP was offered without any supervision [33] or only virtual coaching [27,30] in three studies. On-site assistance from support through the existing seating system, supervision, verbal guidance to actual hands-on assistance was offered during ICP in 10 studies [23,24,31,32,35,36,38–40,44]. The rest of the studies did not explicitly state this condition. With such huge variations among the studies, it was impossible to perform a meta-analysis of the overall results of ICP on postural control and balance for children with CP. Thus, this systematic review narratively summarizes the findings. Table 4 re-groups the studies into those demonstrating favorable, neutral or unfavorable results of ICP towards postural control and balance.

### 2.1. Postural control

Of the 12 studies investigating the effect of ICP on postural control, six studies [23,29,37,38,41,42] have shown statistically significant improvement in the participants (Table 4). Based on available data from three studies [29,37,38], the effect size of the improvement ranged from small (Cohen's  $d < 0.20$ ) to large (Cohen's  $d > 0.50$ ) [45]. Two studies [34,44] showed positive improvement with no statistical analysis. Three studies [30,33,35] found no favorable result towards ICP and one study [43] found the participant increasingly using

compensatory postural control after ICP (Table 4).

### 2.2. Balance

Eleven studies examined the effect of ICP on balance (Table 4). Seven studies [24,26,28,29,31,36,39,40] found statistically significant improvement in balance of the study participants. The effect size from six studies [24,26,28,29,31,36,39,40] ranged from 0.23 to 1.19, i.e. medium to large [45]. One study [32] showed a positive effect on balance without statistical analysis. Three studies [27,35,40] did not find any favorable results towards ICP.

## 3. Discussion

Advances in computer technology make ICP more affordable and clinicians have started to use ICP in rehabilitation for children with CP [6–15,26]. No definitive conclusion can be drawn whether ICP is effective for improving gross motor function in children with CP, due to the overall low study quality and huge variations in ICP protocols among the studies; however promising results have been yielded [6–15,26]. The present systematic review focused on the effect of ICP on postural control and balance in children with CP, on the ground that ICP offers task-specific trunk exercises for children. The same amount of active trunk movements may be less likely in conventional therapy, at least not in such a motivating and fun way. ICP may be more able to encourage a high dose of intensive training for motor learning, in turn enhancing neuroplasticity [17].

### 3.1. Overall study quality of included studies

Ten included studies were RCTs or MSSRDs with more than three participants, while the others were non-RCTs, cohort studies with no

**Table 1**  
Designs and demographic characteristics of included studies.

Study	Study design	Level of evidence	Sample size / Age (years)	Gender	Types of CP/ GMFCS levels	Assessment points
AlSaif and Alsenany 2015 [26]	RCT	II	N = 40, age = 6-10	Not specified	Ix gp- dip n = 20/ III = 20 Cont gp- dip n = 20/ III = 20	Baseline and completion (12 wks)
Barton et al. 2013 [43]	Case report	V	N = 1, age = 10	Male	Dip/ I	Baseline and completion (6 wks)
Bilde et al. 2011 [27]	Cohort study without controls	IV	N = 9, mean age = 10.33 (SD 2.40)	Male n = 5 (56%)	Spastic/ I = 8, II = 1	Baseline and completion (20 wks)
Bonnechere et al. 2017 [28]	Cohort study without controls	IV	N = 10, mean age = 10 (SD 3)	Male = 6 (60%)	Not specified/ I, II and III	Baseline and completion (4 wks)
Brien and Sveistrup 2011 [39]	Multiple baseline single subject ABA design	II	N = 4, mean age = 16 (SD 2.25)	Male = 4 (100%)	Dip n = 3, dys n = 1/ I = 4	Baseline (3-4 assessments in 1 wk), intervention (daily assessments on days 2 to 5) and 1 month (FU, 3 assessments in 1 wk)
Deutsch et al. 2008 [44]	Case report	V	N = 1, age = 13	Male	Dip/ III	Baseline, completion (4 wks) and 3 months (FU)
Gatica-Rojas et al. 2017 [23]	Matched pairs RCT	II	N = 32, mean age = 10.7 (SD 3.2). Dropouts n = 2 in Ix gp and n = 1 in Cont gp.	Ix gp- male = 10 (63%) Cont gp- male = 9 (56%)	Ix gp- hemi n = 4, dip n = 12/ I = 5, II = 11 Cont gp- hemi n = 5, dip n = 11/ I = 6, II = 10	Baseline, 2 wks, 4wks, completion (6 wks), 8 wks (FU) and 10 wks (FU)
Hsieh 2018 [29]	RCT	II	N = 40, Ix gp- n = 20, mean age = 7.33 (1.31), Cont gp- n = 20, mean age = 7.41 (SD 1.54)	Ix gp- male = 14 (70%)	Ix gp- quad n = 11, dip n = 4, dys n = 2, Ataxic n = 3/ II = 10, III = 6, IV = 4 Cont gp- quad n = 12, dip n = 3, Dys n = 2, ataxic n = 3/ II = 10, III = 5, IV = 5	Baseline and completion (12 wks)
Jelasma et al. 2013 [40]	Multiple baseline single subject design	I	N = 14, mean age = 11.36 (SD 1.82)	Male = 8 (57%)	Hemi n = 14/ I = 5, II = 9	Weekly for 8 wks and 16 wks (FU)
Lorentzen et al. 2015 [30]	Non-RCT	III	N = 46, Ix gp- n = 34, mean age = 10.9 (0.4), Cont gp- n = 12, mean age = 11.3 (SD 0.9)	Ix gp- male = 23 (50%)	Ix gp- hemi n = 29, dip n = 1, dys n = 4/ I = 33, II = 1	Baseline, completion (20 wks) and 12 wks (FU)
Luna-Oliva et al. 2013 [31]	Cohort study without controls	IV	N = 11, mean age = 7.91 (SD 2.77)	Cont gp- male = 7 (58%)	Cont gp- hemi n = 9, dip n = 3/ I = 11, II = 1	Baseline, completion (8 wks) and 8 wks (FU)
Meyns et al. 2017 [32]	Non-RCT	III	N = 11, Ix gp- n = 4, mean age = 13.3 (SD 3.8), Cont gp- n = 7, mean age = 10.7 (SD 5.4)	Male = 5 (46%) Ix gp- male = 1 (25%)	Hemi n = 3, dip n = 8/ I = 9, II = 2 Ix gp- dip n = 4/ I to IV	Baseline, every 3-weekly up to 12 wks (completion) and 18 wks (FU)
Ramstrand and Lyngnegard 2012 [33]	Cross-over RCT	II	N = 18, mean age = 13.42 (SD 3.00)	Cont gp- male = 3 (43%) Male = 8 (44%, based on n = 18)	Cont gp- hemi n = 1, dip n = 2, tri n = 1, quad n = 3/ I to IV Hemi n = 9, dip n = 3/ I = 3, II = 9	Baseline and completion (5 wks)
Reid 2002 [34]	Non-RCT	III	Drop-outs n = 6 N = 6, Ix gp- n = 3, mean age = 10.33 (1.53), Cont gp- n = 3, mean age = 10.67 (SD 0.58)	Not specified	Ix gp- dip n = 1, quad n = 2/ I = 1, III = 1, IV = 1	Baseline and completion (4 wks)
Sajan et al. 2017 [35]	RCT	II	N = 20, Ix gp- n = 10, mean age = 10.6 (3.78), Cont gp- n = 10, mean age = 12.4 (SD 4.93)	Ix gp- male = 6 (60%)	Cont gp- dip n = 1, quad n = 2/ I = 1, IV = 1#; V = 1 Ix gp- dip n = 5, tri n = 4, quad n = 1/ II = 1, III = 7, IV = 2	Baseline and completion (3 wks)
Sharan et al. 2012 [36]	RCT	II	Drop-outs n = 2 N = 16, Ix gp- n = 8, mean age = 8.88 (3.23), Cont gp- n = 8, mean age = 10.38 (SD 4.41)	Cont gp- male = 5 (50%) Not specified	Cont gp- dip n = 7, tri n = 1, quad n = 2/ I = 1, II = 2, III = 6, IV = 1 Not specified/ not specified	Baseline and completion (3 wks)
Shih et al. 2010 [42]	Multiple single subject ABAB design	IV	N = 2, age = 8 and 9	Male n = 1 (50%)	Not specified/ IV*	2 baseline and 2 intervention phases

(continued on next page)

Table 1 (continued)

Study	Study design	Level of evidence	Sample size / Age (years)	Gender	Types of CP/ GMFCS levels	Assessment points
Shih et al. 2011 [41]	Multiple single subject ABAB design	IV	N = 2, age = 17 and 18	Male n = 1 (50%)	Spastic quad/ V*	2 baseline and 2 intervention phases
Tarakci et al. 2016 [24]	RCT	II	N = 30, Ix gp- n = 15, mean age = 10.46 (2.69), Cont gp- n = 15, mean age = 10.53 (SD 2.79) Drop-outs n = 8	Ix gp- male = 10 (67%)	Ix gp- hemi n = 7, dip n = 7, dys n = 1/ median = II (range I to II)	Baseline and completion (12 wks)
Velasco et al. 2017 [37]	RCT	II	N = 10, Ix gp- n = 5, mean age = 4.8 (3.0), Cont gp- n = 5, mean age = 11.2 (SD 3.8)	Cont gp- male = 9 (60%) Not specified	Cont gp- hemi n = 7, dip n = 5, dys n = 3/ median = II (range I-III) Not specified/ not specified	Baseline and completion (after 10 sessions)
Waide and Porter 2012 [38]	Cross-over RCT	II	N = 13, mean age = 9.83	Not specified	Not specified/ IV = 2*, V = 11*	Baseline, 3 months (cross-over) and completion (6 months)

Cont gp- control group; CP- cerebral palsy; dip- diplegia; dys- dyskinetic; FU- follow-up; GMFCS- Gross Motor Function Classification Scale; GMFM- Gross Motor Function Measure; hemi- hemiplegia; Ix gp- intervention group; NS- not specified; quad- quadriplegia; RCT- randomised controlled trial; tri- triplegia; wk- weeks.

\* Classified by the present author based on the information of the study. # classified by the study author as level III but re-classified as level IV by the present author based on the information of the study.

concurrent control or case reports (Table 1). The low mean PEDro score of the included studies indicates that the majority of the studies had only a fair study quality, despite the fact that ten studies had level I or II evidence (Tables 1 and 2). The main weaknesses of these RCTs and MSSRDs were lack of blinded participants, therapists and assessors, and no intention-to-treat analysis. It is not possible to blind the participants and therapists during ICP; hence, the maximum possible PEDro score would be 8 for this kind of intervention. Nevertheless, blinded assessments was not explicitly specified in eight of the studies (Table 2). The overall fair study quality of the included studies stands as a precaution in interpreting the research evidence for this intervention [6–16].

### 3.2. Effectiveness on postural control

Three level II studies with high quality [23,29,37] and one level II study with fair quality [38] demonstrated favorable results towards ICP to improve postural control of children with CP. A large effect size was found in improving postural control of the head [37] and medium to large effect sizes in improving postural control of the trunk in the others [29,38]. Another four studies of lower levels of evidence and poor to fair study quality supported this finding (Table 4) [34,41,42,44]. In contrast, one study of level II evidence with fair study quality [35] and two studies of level II or III evidence with poor study quality [30,33] showed ICP was at least as effective as conventional therapy to improve postural control. One case report showed that the participant showed increased co-contraction of his trunk over the pelvis after ICP, i.e. a decrease in postural control but use of a compensatory strategy [43]. ICP was apparently effective in improving postural control in children with CP with medium to large effect sizes, as the studies of higher levels of evidence and higher methodological rigor mostly demonstrated positive results in this aspect. Nevertheless, it is unknown if the three positive effects - improvement in postural control, improvement in head and trunk postures and decrease in sway within base of support - were carried over to the functional skills of the participants, as changes in functional abilities were assessed only in one out of the four studies (Table 3). The minimum dosage of ICP to improve postural control is inconclusive due to lack of adequate information from the studies demonstrating favorable results (Table 3). Also unknown is the importance of on-site guidance for the participants during ICP, as half of the studies did not explicitly state this condition (Table 3). Further studies of high methodological rigor are required before ICP is used to improve postural control of children with CP in clinical settings.

### 3.3. Effectiveness on balance

Regarding balance, favorable results of ICP were found more often in studies of higher levels of evidence and higher study quality with medium to large effect size (Tables 3 and 4). Three studies [27,35,40] showed that ICP was at least as effective as conventional therapy in improving balance of the participants (Table 4). Jelsma et al. (2013) [40] found their participants significantly improved in a standardized outcome measure of balance and running speed and agility but showed no improvement in the timed up-and-downstairs test (Table 3). The contradiction might reflect the fact that the timed up-and-downstairs test requires not only balance but also other motor abilities, e.g. muscle strength in the lower limbs, to achieve a significant improvement. It is reasonable to conclude that ICP could improve balance in children with CP. The majority of the participants were of GMFCS levels I to more-abled III (over 70%, Table 3). The effect of ICP on balance in the more severe groups, i.e. less-abled III and IV, remains unknown. All except two [26,27] studies demonstrating favorable results of ICP explicitly stated that on-site assistance was offered for the participants during the intervention (Tables 3 and 4). It appears that on-site guidance, even if only verbal instructions can maximize the benefit of ICP on balance of the participants. Co-contraction of both agonist and antagonist muscles around the trunk are a common strategy, even for children with mild

**Table 2**  
PEDro scores of included studies.

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Total score
AlSaif and Alsenany 2015 [26]	Y	Y	Y	U	N*	N*	U	Y	Y	N	Y	5
Barton et al. 2013 [43]	N	N	N	Y	N	N	N	Y	Y	N	Y	4
Bilde et al. 2011 [27]	N	N	N	Y	N	N	N	Y	Y	N	Y	4
Bonnechere et al. 2017 [28]	Y	N	N	Y	N	N	N	Y	Y	N	Y	4
Brien and Sveistrup 2011 [39]	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5
Deutsch et al. 2008 [44]	N	N	N	Y	N	N	N	Y	Y	N	Y	4
Gatica-Rojas et al. 2017 [23]	Y	Y	Y	Y	N	N*	U	Y	Y	Y	Y	7
Hsieh 2018 [29]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Jelsma et al. 2013 [40]	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	8
Lorentzen et al. 2015 [30]	N	N	N	Y	N	N	N	N	Y	Y	Y	4
Luna-Oliva et al. 2013 [31]	Y	N	N	Y	N	N	N	Y	Y	N	Y	4
Meyns et al. 2017 [32]	Y	N	N	Y	N	N	N	N	Y	N	N	2
Ramstrand and Lyngnegard 2012 [33]	Y	Y	Y	U	N	N*	U	N	N	Y	N	3
Reid 2002 [34]	Y	Y	U	Y	N	N*	Y	Y	Y	N	N	5
Sajan et al. 2017 [35]	Y	Y	Y	Y	N	N*	U	Y	N	Y	Y	6
Sharan et al. 2012 [36]	N	Y	Y	Y	N	N*	U	N	N	Y	Y	5
Shih et al. 2010 [42]	N	N	N	Y	N	N*	U	Y	Y	Y	N	4
Shih et al. 2011 [41]	N	N	N	Y	N	N*	U	Y	Y	Y	N	4
Tarakci et al. 2016 [24]	Y	Y	Y	Y	N	N*	U	N	N	N	Y	4
Velasco et al. 2017 [37]	Y	Y	Y	N	N	N*	U	Y	Y	Y	Y	6
Wade and Porter 2012 [38]	Y	Y	Y	Y	N	N	U	N	N	Y	Y	5
											Mean (SD)	4.7 (1.3) Range 2–8

Y- yes, N- no, U- unknown as not specified in study.

Q1. Eligibility criteria were specified.

Q2. Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received).

Q3. Allocation was concealed.

Q4. The groups were similar at baseline regarding the most important prognostic indicators.

Q5. There was blinding of all subjects.

Q6. There was blinding of all therapists who administered the therapy.

Q7. There was blinding of all assessors who measured at least one key outcome.

Q8. Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups.

Q9. All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by “intention to treat”.

Q10. The results of between-group statistical comparisons are reported for at least one key outcome.

Q11. The study provides both point measures and measures of variability for at least one key outcome.

\* Due to the nature of the intervention, it was not possible to blind the participants and therapists during the intervention. Hence, the entries for Q5 and Q6 must be a “no”, despite the fact that some studies did not explicitly state this in their studies.

CP, when their balance is challenged [3]. On-site guidance from a therapist may discourage the children from using this default compensation in favor of learning to selectively control their trunk during ICP. This speculation should be verified with future studies. Based on the present evidence, the minimum effective dosage of ICP is 25 to 30 min per session, 2 to 3 sessions per week for 3 weeks.

### 3.4. Medium- to long-term effect of ICP

For the seven studies examining the medium-term effect of ICP, only six [23,30–32,39,40] reported the results, of which five [23,30,31,39,40] performed statistical analyses of the results. While four studies [30,31,39,40] showed a sustained effect of ICP at 4–16 weeks post-intervention, one study [23] of high evidence level and high study quality, with the largest sample size of 32, did not find a sustained effect of ICP at 8 weeks post-intervention. The medium to long-term effect of ICP remains inconclusive and requires further investigation. Lastly, for those studies [23,24,28,31,35–37,40,44] explicitly comparing ICP with conventional therapy, more favorable results were found towards ICP with small to large effect sizes (Cohen’s  $d = 0.23-0.80$ ), especially in balance (Tables 3 and 4).

### 3.5. Study limitations

This review has its limitations. One person did the selection and rating of the studies and data retraction. Nevertheless, the studies were selected under clear and defined selection criteria and rated using the standardized and stringent PEDro scale, all of which would minimize

bias during the process. Only full publications in English-language peer-reviewed journals were included, raising the possibility of selection bias.

### 3.6. Future directions

The overall low study quality of the included studies remains a concern when gathering research evidence of this modality on postural control and balance for children with CP. More rigorous methodologies, such as larger sample sizes, use of comparable control groups, blinded assessors, intention-to-treat analysis and provision of clear group results, are recommended. Evidence on the effectiveness of ICP for those of GMFCS levels less-abled III to V remains scarce.

## 4. Conclusion

Twenty-one studies were included examining the effectiveness of ICP on postural control and balance for children with CP. Half of the studies were of levels I or II evidence while the majority were of poor to fair methodological rigor. ICP seemed to be more effective than conventional therapy in improving postural control and balance in children with CP with medium to large effect sizes. The minimal dosage for balance training is 25–30 minutes per session, 2–3 sessions per week for 3 weeks. Future studies are required to verify the role of on-site guidance of children during ICP to maximize the effect of this treatment on postural control and balance of participants, and to investigate the medium to long-term effect of ICP and its effect on children with more severe CP.

**Table 3**  
Summary of studies: outcomes, measures and results.

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation		
Alsaif and Alsenany 2015 [26]	Nintendo Wii Balance board/ 20 min./session, 7 sessions/ week, 12 weeks. not specified position	Motor function	mABC		Sign improvement in Ix gp in Manual Dexterity, Aiming and Catching and Balance subtests (no p value provided). NS for Cont gp (no p value provided) Sign improvement in Ix gp (no p value provided). NS for Cont gp (no p value provided) Sign improvement in Ix gp (no p value provided). NS for Cont gp (no p value provided)	No	Not specified
Barton et al. 2013 [43]	CAREN system (MoteK Medical)/ 30 min./session, 2 sessions/week, 6 weeks in high kneeling position	Postural control Segmental trunk control	Kinematic measures to quantify pelvis-trunk coupling SATCo	Increased coupling of pelvis and trunk, i.e. decreased selective control Static control increased from 2 to 4, active remained same (1), reactive increased from not applicable to 2		Not specified	Not specified
Bilde et al. 2011 [27]	Specifically designed game console called MiTii/ 30 min./ session, 1 session/day, 7 days/ week, 20 weeks in various positions	Gait pattern Motor and process skills UL function Muscle strength Muscle strength	Gait Deviation Index Assessment of Motor and Process skills Assisting Hand Assessment Isometric muscle strength in knee extensors and flexors Lateral and frontal step-up	Minimal change Sign improvement in motor ( $p < 0.001$ ) and process ( $p < 0.05$ ) skills NS Sign increase in step counts (lateral, $p < 0.01$ ; frontal, $p < 0.001$ ) sign increase in step count ( $p < 0.01$ )		Not specified	Virtual coaching via internet from a therapist
Bonnechere et al. 2017 [28]	Nintendo Wii Balance board/ 30 min./session, 1 session/ week, 4 weeks in sitting	Muscle strength Balance Endurance Endurance Visual perceptual skills Trunk control	Sit-to-stand Romberg 30 seconds with eyes open Bruce treadmill test 6-minute walk test Test of Visual Perceptual Skills Trunk Control Measurement Scale	Tested on 4 children only. NS Sign increase in duration ( $p < 0.05$ ) Sign improvement in figure ground test ( $p < 0.05$ ) and total score ( $p < 0.01$ )	Tested on 4 children only. NS	Yes	Not specified

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Table 3 (continued)

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation		
Brien and Sveistrup 2011 [39]	GestureTek's Interactive Rehabilitation and Exercise/ 90 min./session, 2 session/day, 5 consecutive days in sitting	Balance and mobility Endurance Balance	Community Balance and Mobility Scale 6-minute walk test Timed up and down stairs	Sign improvement at intervention phase and FU phase when compared to baseline (no <i>p</i> value provided) Sign improvement at intervention phase and FU phase when compared to baseline (no <i>p</i> value provided) Sign improvement at intervention phase and FU phase when compared to baseline (no <i>p</i> value provided) NS			On-site verbal guidance from a therapist
Deutsch et al. 2008 [44]	Nintendo Wii Balance board/ 60-90 min./sessions, 11 sessions over 4 weeks in sitting and standing	Gross motor skills Visual perceptual skills UL function Gross motor skills Postural control	GMFIM Dimension E Test of Visual Perceptual Skills 3 <sup>rd</sup> ed Quality of Upper Extremity/ Skills Test GMFIM Dimensions D and E Postural Scale Analyzer	Improvement shown in all domains, except sequential memory Not reported Not reported Decrease in postural sway when eyes open and closed, more symmetrical weight distribution medial-lateral when eyes closed and anterior-posterior when eyes closed	Yes		On-site hands-on guidance from a therapist
Gatica-Rojas et al. 2017 [23]	Nintendo Wii Balance board/ 30 min./session, 3 sessions/ week, 6 weeks in sitting and standing	Functional mobility Postural control Postural control Postural control	Functional mobility COP sway under eyes closed or eyes open when standing still Sign decrease in COP sway from baseline to wk 6 ( <i>p</i> = 0.044) and from wk 2 to 6 ( <i>p</i> = 0.023) but sign increase from wk 6 to wk 10 ( <i>p</i> = 0.001) and from wk 8 to 10 ( <i>p</i> = 0.034) when eyes open Sign increase in anterior-posterior trajectory from baseline to wk 2 ( <i>p</i> = 0.015) and increase from baseline to wk 8 ( <i>p</i> = 0.03) when eyes closed Sign decrease in anterior-posterior velocity from wk 2 to wk 6 ( <i>p</i> = 0.03) and increase from baseline to wk 8 ( <i>p</i> = 0.044), wk 4 to wk 8 ( <i>p</i> = 0.023) and wk 6 to wk 8 ( <i>p</i> = 0.011) when eyes closed	Increased in independent walking distance during training (4.6 m to 45.7 m) and at FU (to 76.2 m)	No		On-site hands-on guidance from a therapist

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Table 3 (continued)

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		Contextual factors	ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation			
Hsieh 2018 [29]	Specifically designed game console/ 40 min./session, 5 sessions/week, 12 weeks, in sitting	Postural control	Midot posture scale analyzer	Sign difference, Ix gp > Cont gp ( $p < 0.007$ )			Not specified	Not specified
		Balance	Berg Balance Scale Fullerton Advanced Balance Scale Timed-up-go	Sign difference, Ix gp > Cont gp ( $p < 0.007$ ) NS btw gps NS for both gps Sign difference, Ix gp > Cont gp ( $p < 0.007$ )				
Jelsma et al. 2013 [40]	Nintendo Wii Balance board/ 25 min./session, 4 sessions/week, 3 weeks in standing	Balance	BOT-2 balance subtest and running speed and agility subtest	Sign increase in balance from baseline to completion ( $p < 0.001$ ) and baseline to FU ( $p = 0.043$ ) NS			No	On-site verbal guidance from a therapist assistant
Lorenzen et al. 2015 [30]	Specifically designed game console called MiTi/ 30 min./session, 1 session/day, 20 weeks in various positions	Balance Motor and process skills	Timed up and down stairs Assessment of Motor and Process skills	Sign improvement in Ix gp in motor ( $p < 0.001$ btw baseline and completion) and process ( $p < 0.001$ btw baseline and completion) skills and maintained at FU ( $n = 28$ ). NS for Cont gp ( $n = 10$ , all $p > 0.05$ )			Not specified	Virtual coaching via internet from a therapist
		UL function	Assisting Hand Assessment	Sign improvement in Ix gp in scale ( $p < 0.001$ btw baseline and completion) and sum ( $p < 0.001$ btw baseline and completion) scores and maintained at FU ( $n = 27$ ). NS for Cont gp ( $n = 9$ , all $p > 0.05$ )				
		Muscle strength	Lateral step-up	Sign improvement in Ix gp ( $p < 0.001$ btw baseline and completion) and maintained at FU ( $n = 20$ ). NS for Cont gp ( $n = 11$ , $p = 0.93$ )				
		Muscle strength	Sit-to-stand	Sign improvement in Ix gp ( $p = 0.01$ btw baseline and completion) and maintained at FU ( $n = 25$ ). NS for Cont gp ( $n = 11$ , $p = 0.58$ )				
		Muscle strength	Half kneel-to-stand	Sign improvement in Ix gp ( $p < 0.03$ btw baseline and completion) and maintained at FU ( $n = 21$ ). NS for Cont gp ( $n = 11$ , $p = 0.89$ )				
		Postural control	Maintain centre of gravity, sway velocity and total trace length during Romberg 30 seconds test with eyes open	NS for Ix gp ( $n = 31$ , all $p > 0.05$ ) and Cont gp ( $n = 9$ , all $p > 0.05$ )				
Luna-Oliva et al. 2013 [31]	Xbox 360 Kinect/ 30 min./session, 2 sessions/week, 8 weeks, not specified positions	Motor and process skills	Assessment of Motor and Process Skills	Motor: sign improvement between 3 time-points (all $p = 0.003$ )			Yes	On-site supervision of a therapist (continued on next page)

Table 3 (continued)

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation		
		Balance	PRT				
		Walking speed	10-meter walk test		sign improvement between baseline and wk 8 ( $p = 0.013$ ) and between wk 8 and wk 16 ( $p = 0.024$ )		
		Gross motor skills	GMFM Dimensions D and E		sign improvement between baseline and wk 16 ( $p = 0.013$ ) and between wk 8 and wk 16 ( $p = 0.024$ )		
		Balance	Trunk Control Measurement Scale		sign improvement between baseline and wk 8 ( $p = 0.008$ ) and between baseline and wk 8 ( $p = 0.015$ )	Yes	On-site verbal guidance from a therapist
		Postural control	Change of COP in modified sensory organization test	NS (all $p > 0.05$ )	Improvement in scores in both gps and the increase in Ix gp seemed higher	Not specified	No
		Trunk control	Sitting Assessment for Children with Neuromotor Dysfunction		Improvement in scores in Ix gp but not in Cont gp	Yes	Not specified
		Postural control	Static posturography	NS		Yes	On-site verbal guidance from a therapist
		Balance	Pediatric Berg's Balance Scale		NS btw gps Sign improvement in both gps (Ix gp- $p = 0.017$ and Cont gp- $p = 0.012$ )		
		Balance	Box and Block test	NS btw gps Sign improvement in both gps (Ix gp- $p = 0.005$ and Cont gp- $p = 0.015$ )			
		UL function	Quality of Upper Extremity Skills Test		NS btw gps Sign improvement in grasp ( $p = 0.039$ ), dissociated movements, total score ( $p = 0.027$ ) in Ix gp		
		Visual-Perceptual Skills	Visual-Perceptual Skills	NS btw gps Sign increase in Cont gp ( $p = 0.017$ )			
		Walking speed and endurance	1-minute walk test		NS btw gps Sign improvement in speed in both gps (Ix gp- $p = 0.017$ and Cont gp- $p = 0.043$ )		
		UL function	Manual Ability Classification System		Sign improvement in endurance both gps (Ix gp- $p = 0.028$ and Cont gp- $p = 0.012$ )	Yes	On-site supervision of a therapist
		Balance	Pediatric Balance Scale		Sign improvement in both gp ( $p < 0.05$ ) Sign improvement in both gp		(continued on next page)

Table 3 (continued)

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		Contextual factors	ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation			
Shih et al. 2010 [42]	Nintendo Wii Balance board plus specified device to measure correct posture/ 3 to 5 sessions/day, not specified duration of baseline and intervention phases, in standing	Participants perception Postural control	Level of participation, satisfaction, cooperation and motivation Duration of maintaining corrected standing posture	Sign increase in duration to keep corrected posture during intervention phase, not in baseline phases ( $p < 0.01$ for both children)	Sign difference, Ix gp > Cont gp ( $p < 0.05$ )	Sign higher in Ix gp than Cont gp (all $p < 0.02$ )	Not specified	Not specified
Shih et al. 2011 [41]	Nintendo Wii Balance board plus specified device to measure correct posture/ 3 to 5 sessions/day, not specified duration of baseline and intervention phases, in sitting	Postural control	Duration of maintaining upright head posture	Sign increase in duration to keep upright head posture during intervention phase, not in baseline phases ( $p < 0.01$ for both participants)			Not specified	Not specified
Tarakci et al. 2016 [24]	Nintendo Wii Balance board/ 20 min./session, 2 sessions/ week, 12 weeks, not specified positions	Balance	Functional forward reach test		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )		Yes. Cont gp had extra balance training (same dosage at Ix gp)	On-site hands-on guidance from a therapist
		Balance	Timed-up-go		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )			
		Muscle strength	Sit-to-stand test		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )			
		Participants performance	Score and duration of ICP game		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )	Sign difference, Ix gp > Cont gp ( $p < 0.001$ )		
		Walking speed	10-metre walk test		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )			
		Balance	10 steps climbing test		Sign difference, Ix gp > Cont gp ( $p < 0.001$ )			
		Activities of daily living	Wee-FIM total		NS for both gp		Yes	Not specified
Velasco et al. 2017 [37]	ICP controlled with ENLAZA/ 25-30 min./session, 10 sessions, in sitting	Gross motor skills Participants perception	Items 21 and 22 of GMFMS-88 to assess head control in supported sitting Visual analogue scale to grade level of head control (0- no head control, 100- perfect head control) by			Sign improvement in Ix gp and Cont gp ( $p < 0.05$ )		

(continued on next page)

Table 3 (continued)

Study	Equipment used/ dosage	Outcomes of interest	Measures	Components of health		ICP as additional therapy to usual therapy?	ICP under supervision?
				Body structures/ functions	Activities and participation		
Wade and Porter 2012 [38]	Specifically designed game console/ Not specified dosage, in sitting	Participants perception	parents, children and therapists Goal Attainment Scale				
		Trunk control	Trunk Control Measurement Scale		Sign improvement in Ix gp and Cont gp ( $p < 0.05$ )		
		Range of movements	Active range of movement in flexion-extension, lateral flexion and rotation of head	NS for both gps	Sign improvement in Ix gp ( $p < 0.05$ )		
		Postural control	Chailey Levels of Ability		Sign difference at shoulder girdle and spinal profiles ( $p < 0.05$ )		No but some participants were fully supported in wheelchair during ICP
		Trunk control	Sitting Assessment for Children with Neuromotor Dysfunction		Sign improvement in overall scores for rest and reach phases ( $p < 0.05$ ). Sign improvement in associated postural reaction during rest phase, proximal stability rating and leg extension during reach phase ( $p < 0.05$ )		Not specified

BOT-2- Bruininks-Oseretsky test of Motor Proficiency 2<sup>nd</sup> Edition; btw- between; Cont gp- control group; COP- centre of pressure; FU- follow-up; ICP- interactive computer play; Ix gp- intervention group; mABC- Movement Assessment Battery for Children 2<sup>nd</sup> Edition; NS- non-significant; wk- weeks; WeeFIM- Functional Independence Measure for Children.

**Table 4**  
Summary of evidence of ICP on balance and postural control in children with CP.

Outcomes by dimensions of disability	Favour ICP <sup>a</sup>		No difference	Not favour ICP
	Statistically significant difference ( $p \leq 0.05$ )	Not statistically analysed	No statistically significant difference ( $p > 0.05$ )	Not statistically analysed
Postural control	<b>II-H [23]</b> (inadequate data to calculate effect size) <b>II-H [29]</b> (effect size = 0.10-0.94) <b>IV-F [42]</b> (inadequate data to calculate effect size) <b>IV-F [41]</b> (inadequate data to calculate effect size) <b>II-H [37]</b> (effect size = 0.99) <b>II-F [38]</b> (effect size ≈ 0.44-0.69)	<b>V-F [44]</b> <b>III-F [34]</b>	<b>III-F [30]</b> <b>III-F [33]</b> <b>II-H [35]</b>	<b>V-F [43]</b> (inadequate data to calculate effect size)
Balance	<b>II-F [26]</b> (effect size = 1.01) <b>IV-F [28]</b> (effect size = 0.23) <b>III-F [39]</b> (inadequate data to calculate effect size) <b>II-H [29]</b> (effect size = 0.99-1.19) <b>I-H [40]</b> (effect size = 0.63) <b>IV-F [31]</b> (effect size = 0.77) <b>II-F [36]</b> (effect size = 0.80) <b>II-F [24]</b> (reported effect size = 0.19-0.65)	<b>III-P [32]</b>	<b>IV-F [27]</b> <b>I-H [40]</b> <b>II-H [35]</b>	

Studies in bold were those explicitly comparing ICP with conventional therapy. Roman numeral- level of evidence according to research design. P- poor quality of the study; F- fair quality of the study; H- high quality of the study according to the PEDro score of each study.

\* Calculated based on the published group data (if provided and adequate) of the included studies using recommended calculation method by Rosnow and Rosenthal (1996) [46].

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.gaitpost.2019.07.122>.

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