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Feasibility of a randomised controlled trial to evaluate home-based virtual reality therapy in children with Cerebral Palsy

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Abstract

Purpose: Virtual reality therapy (VRT) for children with Cerebral Palsy (CP) is promising but studies of effectiveness are limited. A feasibility study is merited prior to embarking on a full randomised controlled trial (RCT).

Method: A 12-week, 2-group, parallel feasibility RCT using Nintendo Wii Fit™ aimed to test appropriateness of measures and acceptability of method. Children aged 5–16 years, with ambulatory CP and able to follow simple instructions were allocated by minimisation with a random element to two groups; one supported (SG) by physiotherapists using an individualised programme of activities and the other unsupported (USG) by therapists with children having free choice. A variety of indicators (e.g. recruitment, adherence, usefulness of measurement tools) were employed to assess acceptability and feasibility. Memory data from consoles and patient diaries were recorded for 12 weeks to document session times and activities. Physiotherapists, blind to allocation, measured outcomes at baseline, week 6 and 12.

Results: Forty-four children were assessed for eligibility: 31 consented and 30 randomised (15 per group); 21 completed the study and were analysed, 10 in SG group, 11 in USG group. There were no adverse effects. Discontinuation by 9 children resulted from tiredness, after-school activities, homework, surgery, technical difficulties or if negative system feedback occurred. SG completed a mean of 19/36 (IQR 5-35) possible sessions; USG completed a mean of 24/36 sessions (IQR 8-36). Change in GMFM scores varied by CP severity.

Conclusion: Intervention acceptable and appears to show potential therapeutic benefit warranting larger confirmatory study. GMFM appears valid as a measurement tool, but with additional GMFM adjuncts to improve sensitivity. Other measurement tools perhaps unnecessary e.g. BOT2 as measuring lasted too long lessening acceptance. No adverse events or side effects. A full trial to assess clinical and cost effectiveness of VRT using commercial systems is feasible with minor adaptation to current method, as an acceptable mode or adjunct to therapy for children with CP.

Trial registration: International Standard RCT number 17624388

Keywords: feasibility, RCT, virtual reality therapy, Cerebral Palsy

Subject classification codes: include these here if the journal requires them

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Introduction

Cerebral Palsy (CP) is an umbrella term for a collection of disorders that occur as a result of primary non-progressive damage to the developing foetal or infant brain, occurring at a rate of approximately 2 per 1000 live births in the UK or 254,000 live births per annum, globally [WHO 2005]. The resulting disruption to the developing brain affects muscle tone and strength, and impacts on the possibilities for fluent movement and physical activity. Co-morbidity can often occur with other disorders which further affects communication, cognition, perception and sensation [Rosenbaum et al 2007].

In the UK, children with CP experience a decline in the amount of therapeutic time they receive as they age, from 12 hours a year for 0-6 year olds, to 7 hours for 12-18 year olds [Coombe et al 2012]. Further, a reduction in therapeutic exercise is exacerbated by a general resistance to home-based physical activity [Coombe et al 2012, Bryanton et al 2006, Ferizzi et al 2003]. Unsurprisingly, children with more severe and complex impairments experience the most therapeutic input, leaving ambulatory and older children with CP around 2 hours of therapy per year [Bryanton et al 2006, Fedrizzi et al 2003].

To counteract poor access to therapy, new approaches are needed. To be practicable, new home and school-based interventions need to be low-cost, easily

deployable and flexible. Whilst motor learning theory supports intensive task focused therapies for CP, poor motivation has been experienced in current therapies with insufficient applicability to daily function. [Chen et al 2012, Deutsch et al 2008, Esculier et al 2012, Gordon et al 2012, Miller et al 1995].Therapeutic modes thus need to be both motivating and responsive to the needs of families and be developed with direct input from families of children with CP to ensure greater alignment and applicability to daily function. Virtual reality therapy (VRT) carried out in the home may be one avenue for increasing engagement with therapy and improving children's outcomes.

Virtual reality therapy

As digital technology becomes more prevalent and pervasive for the current millennial generation(s) of "digital natives" [Prensky 2001], there has been a parallel and unprecedented growth in assistive and rehabilitation digital technology for children with additional needs [e.g. see van Hedel and Aurich 2016]. However, practical frameworks that align technology to clinical need remain elusive [van Hedel and Aurich 2016]. In particular; pragmatic questions remain regarding issues of acceptability, feasibility, and patient data security for physical activity with smartphones, GPS, and use of large-scale patient data sets [e.g. Huckvale et al 2015]. Scrutiny is required to ensure digital healthcare services are provided that are appropriately evidence-based, cost-effective, and fit for purpose. Voices of dissent even suggest that digital technology may be "more hype than hope" [Labrique et al 2013].

One avenue for digitized patient care is in the use of virtual reality therapy (VRT) that uses motion capture digital technology to assist as part of a therapeutic treatment programme [Bonnechere et al 2014, Levac et al 2012]. A recent study by this

research team identified the potential of VRT in the home as supportive to active therapy intervention, and is welcomed by children and families although a clearer understanding of the potential impact is needed [Farr et al 2017]. Commercial systems such as the Nintendo Wii Fit™, Xbox Kinect™, or bespoke systems such as Mitii™ have all been tested to date with varying success in: stroke rehabilitation, dementia, children with developmental coordination disorder, acquired brain injury and CP [Hammond et al 2014, Jelsma et al 2012, James et al 2015]. Recent results also suggest that therapy with the Wii Fit in-clinic is more beneficial than in-clinic physiotherapy, so the Wii Fit appears to provide statistical benefits beyond standard intervention [Gatica-Rojas et al 2016]. However, studies are often beset with problems of inadequate sample size [e.g. Ramstrand et al 2012], standardisation of measurement tools [Farr et al 2017], adherence and dosage within programmes of therapy, the role of the therapist, and alignment of aims with daily life skills [Levac et al 2016]. For example, James et al. [2015] demonstrate the 'Move it to improve it' (Mitii™) VRT system is partially effective for improving activities of daily living (ADLs) in children with unilateral CP over a 20 week period, but problems were still experienced in sustaining the novelty of the intervention after the first 20 hours of therapy.

One in four children are reported to have a video game console such as the Nintendo Wii or Sony PlayStation, or more recently the Xbox Kinect in the home [Labrique et al 2013]. A recently published survey [Farr et al 2017] suggests this number may be far higher, with 97% of families in possession of a commercial games console, with active gaming consoles such as the Xbox Kinect making up 68% of total ownership. Families of children with CP reported that as many as 48% (28/61) of survey respondents already used or attempted to use the Wii Fit for therapeutic purposes [Farr et al 2017]. This raises the possibility of an additional motivating tool in the home

121 which may be supported by physiotherapy directed activities, which could enhance
122 patient continuity for home-based exercise regimes.
123 The prohibitively high costs of bespoke systems for physiotherapy interventions,
124 takes access to such technologies beyond the reach of most patients [James et al 2015]
125 and services. To address this issue our focus is on identifying affordable options, with
126 the most likely candidate technology being modified entertainment and exercise
127 systems that are already available. There is "great opportunity to use interactive
128 technology as a holistic intervention to address broad ranges of impairments"
129 [Ramstrand et al 2012]. Health inequality could also be reduced by allowing individuals
130 to carry out the intervention at home, with their family, and at a time of their choosing
131 [Levac 2016], alongside personal goal setting, which is paramount in rehabilitation
132 practice [Levac 2016, Green et al 2011]. As the gap between research and practice is
133 narrowing, work is more gradually focusing on the integration of VR and serious games
134 into therapy according to three key elements; prevention, participation and plasticity
135 [Deutsch et al 2017]. Our work here focuses on beginning to understand low-cost
136 therapeutic participation in the home.
137 Our overall objective was to assess the feasibility of running a multicentre RCT
138 of home based therapeutic use of the Wii Fit in children with ambulatory cerebral palsy.
139 This included assessment of a variety of tools to measure any therapeutic benefit,
140 whether physical or psychodynamic. A wide variety of measures assessed home-use
141 using an off the shelf system, the Nintendo Wii Fit™. Before embarking on a definitive
142 trial, we have undertaken a feasibility study to see if VRT using commercially available
143 systems may be one avenue to increasing therapeutic engagement with children with
144 CP. If the Wii is shown to be a worthwhile method of applying physical therapy,
145 savings could be made on immediate face-to-face physiotherapy with a potential impact

on the number of hours of therapy completed by older children with CP and those who are ambulatory.

Study Aims

The primary aim was to explore the feasibility of a future multicentre RCT to test the effectiveness and cost effectiveness of a commercially available console for Virtual Reality as therapy adjuncts in children with ambulatory CP. Therefore we sought to investigate whether procedures for recruitment attracted sufficient participants, if children adhered to the recommended programme, whether proposed measurement tools and methods of analysis were appropriate, and resource implications/costs in relation to outcomes.

We aimed to estimate the precision of group differences for our five main outcome measures, to begin to gain greater clarity of the sensitivity of these measures to detect relevant change as well as the potential utility of these measures in a definitive RCT.

We additionally wanted to investigate whether the treatment can be offered through physiotherapy services in the NHS, if there is fidelity to the delivery of the treatment, what outcomes are important to measure, the profile of children for whom the treatment may be effective and not effective, and how prior home-use and availability of consoles in the home impacts on treatment.

Two parallel streams of public and patient involvement in Sussex and Devon also informed the research. Parents in both groups agreed that getting children to do regular therapy exercises is a struggle. Parents perceived that using Wii Fit active computer games would be popular with children and families, and improve adherence to therapy programmes. Initial work on this project involved testing out not only the Nintendo Wii Fit, but also the use of Microsoft Kinect technology. We held a parent consultation day

in Sussex and our two co-applicants emerged from this and expressed interest in taking part in the study.

Method

This study was approved by the Lancaster National Research Ethics Committee (NW1499), International Standard RCT number 17624388. All materials were written, and appropriately modified with parent advisors and Peninsula Cerebral Research Unit for Childhood Disability Research family faculty.

Recruitment and Consent

Children with CP were identified from clinical lists kept by Community NHS Trust Child Development Teams (CDT) in a county in south-east England (see figure 1 for process of consent). Families were provided information about the study by their regular clinical team during appointments or through the post. The opportunity to take part in the trial was advertised through posters, or flyers distributed to clinicians at local study days, study presentations to CDTs or via the local clinical research network. Participants were then also able to self-refer to the research team who checked suitability with the child's CDT. After participants initially confirmed interest in the study to their clinical team or through self-referral there was a 24 hour cooling off time. Participants were then approached by a research assistant to book an appointment to check eligibility and obtain written consent. A record of participation interest and consent was made on clinical notes so as not to duplicate contact with families, and was also kept of families not wanting to take part to determine the likely size of population needed to run a definitive RCT (see figure 2). Recruitment took place between 27/7/2015 and 10/5/2016 and follow-up ended on 2/8/2016. Based on local population size and prevalence predictions we anticipated that by recruiting children of school age

(i.e. 5 to 16) we would be able to reach a target of 30 children, assuming a 40% positive response rate. Julious (2006) recommended that a pilot trial should have at least 12 participants per group for the analysis, therefore allowing a drop out of 20% post randomization.

Inclusion criteria

Ambulatory children aged 5 to 16 years with bilateral and unilateral CP were invited to take part. Children included were ranked on the Gross Motor Function Classification Scale (GMFCS) levels I and II [Schroder et al 2011]. At GMFCS I and II children are able to walk independently over short distances without use of walking aids. Children were also expected to be able to follow simple task instructions. Children had to be under the clinical management of the local Community NHS Trust.

Exclusion criteria

Children with epilepsy who were photosensitive or had had a seizure within the previous year or were taking anticonvulsant medication were also excluded.

Randomisation

Children with CP (GMFCS levels I/II) were randomised with Minimpy [SourceForge.net] using minimisation [Altman and Bland 2005] with a 70% probability of allocating to the group which minimises imbalance on variables that could influence the outcome, namely gender, type of cerebral palsy (unilateral or bilateral), and age band (primary under 11 years or secondary school age over 11 years). Table 1 shows the balance of minimisation.

Randomised Groups

Children were allocated to either a physiotherapist supported group with prescribed games (SG) or an unsupported group with freedom over game choice (USG). The SG was given a structured home-therapy programme. The USG had free-usage in order to control for the Hawthorne effect and further, it was considered unethical to withdraw families' own devices for the 12-weeks of the study.

Measurement tools

Study Outcome measures

Five measurement tools were employed, and considered for their measurement properties, suitability for detecting change, and potential to support the estimation of a sample size of a future RCT. Clinical measurements were taken by a physiotherapist blind to allocation and were assessed at baseline (6 weeks, and 12 weeks).

The **Gross Motor Function Measure-66** (GMFM-66) is a clinical measure designed to evaluate change in gross motor function in children with Cerebral Palsy [2]. This could potentially be a primary measure in future studies as it is already a *de facto* gold standard [e.g. see Nelson et al 2006 for details] for measuring impact on motor function for children with CP.

There are five dimensions to assessment; lying and rolling, sitting, crawling and kneeling, standing, and walking, running and jumping [Nelson et al 2006]. This tool has a track record of use in studies with children with Cerebral Palsy and VRT [Chen et al 2012, Gordon et al 2012, Deutsch et al 2008,]. Although GMFM-66 is considered to be better clinically than the longer GMFM-88, it has been shown to report changes more slowly postoperatively in gross motor function compared to GMFM-88 [Josenby et al

2009, Wang et al 2006]. For work with assisted technologies, GMFM-66 is considered to be a sensitive tool capable of detecting gross motor improvement in children with CP [Schroder et al 2011].

The Timed up and Go test (TUG) measures mobility, and active and static balance. It involves recording the time taken to get up from a chair, walk three metres, walk back to the chair and then sit down. It is conducted using the normal mobility aids an individual may need. This tool has a track record of use in studies with children with Cerebral Palsy and VRT [Schroder et al 2011, Mitchell et al 2012]. It can be used on children as young as three years old and has high detection rates for functional mobility [Williams et al 2005]. The test has high reliability within session (intra class correlation of 0.99) and test re-test of the same level [Dhote and Prema 2012]. Whereas the GMFM measures gross motor skills the TUG has been found to show accompanying changes in movement speed [Campos et al 2011]

Bruininks-Oseretsky test of motor proficiency – short form, Balance subscale, and Running, Speed and Agility subscale (BOT2) [Cairney et al 2009]. This tool was included because of its effective sensitivity to change in motor proficiency conducted during our own pilot study with children with developmental coordination disorder [Hammond et al 2014]. Additionally we are unsure of potential floor and ceiling effects, which this feasibility RCT study assessed.

Goal Attainment Scale (GAS) scores patient's individual goals, is particularly sensitive to change, and encourages patient intervention [Kirusek et al 1994]. This tool has been used in studies with children with Cerebral Palsy and VRT, but has been included because of its effective prior use in establishing and maintaining interest in patient intervention [Green et al 2011].

Two of the four tools have a track record of suitability (GMFM and TUG) whilst BOT2 and GAS scores are untested with VRT and CP. One aspect of the feasibility study investigated how appropriate these measurements would be for gathering data from which effectiveness could be assessed, what might be the primary outcome measure, and how the four work together, if at all, as useful clinical tools for showing improvements in functional balance and secondary effects following VRT in children with CP.

Psychosocial Outcomes were measured through recorded diaries (see appendix 1) of the child and parental experience of using VRT. The **Strengths and Difficulties Questionnaire (SDQ**) which reflects, in this instance, parent report of social and emotional behaviour was also administered at the start and end of the study to assess potential broader impacts [Goodman 2001].

The Edinburgh handedness inventory [Oldfield 1971, Veale 2014] is a short four question check asking whether a child uses one hand predominantly for a certain task such as writing, throwing, using a toothbrush (‘always’, ‘usually’, ‘both equally’) and produces a laterality quotient of either left, right or mixed handed. This measurement was used as children and parents were often unsure which hand was predominant if the child had bilateral cerebral palsy.

All measurements were completed by senior physiotherapists blind to treatment allocation at baseline, 6 and 12 weeks

Diaries of games undertaken were utilised to provide information of subjective ratings of acceptability and enjoyment. Participants also took part in a postal questionnaire on physical activity and participation in daily tasks. This questionnaire was added as an amendment to the study and the results have been published [Farr et al 2017].

Public and Patient Involvement

Two parent carer co-applicants of the research project became consultant parent advisers to the steering committee. There was also support from a parent carers working group in the PenCRU Family Faculty at the University of Exeter Medical School. As a result Parents became an integral part of the research project supporting consulting of drafts of documents to be used during the project including information sheets and consent forms. Parent advice ensured these were informative and accessible.

Procedures

Data Collection

Data was collected by recruited 5senior physiotherapists (3 band 7's, 2 band 8's) over a period of 13 months at four NHS child development centres across one county in South-East England. All data was collected utilising clinical rooms. The size of each room, repeat availability for follow-up, and variety of equipment in each clinic varied across centres.

Schedule for Follow-up

Both groups were given a Nintendo Wii Fit package and recommended by the consenting team and physiotherapists to play for 30 minutes, 3 times per week for 12 weeks using the Nintendo Wii Fit plus games (see appendix 2 for programme) and asked to keep a diary of what they did on each occasion.

Children in the SG were supported by a physiotherapist (not the physiotherapist who carried out measurements) who contacted the child every two weeks by telephone to assign games, and subsequently checked how the prescribed programme of activity was progressing and suggested scaffolding for extension of games and activities for

motor progress, as necessary. In the USG fortnightly phone contact was offered for general queries e.g. was the system working? However, no specific advice on games and activity scaling was provided. A record of the number of calls, duration, voice messages and summary of conversations was made.

No repeat phone calls were made when there was no answer.

Analyses

Continuous variables were summarised using means and standard deviations, medians and interquartile ranges, and categorical and binary variables using frequencies and percentages. Normality of outcomes was not assumed so differences in outcomes measures between the groups are presented with bootstrapped bias corrected and accelerated 95% confidence intervals. All analysis was done using Stata software, version 14.2 [StataCorp 2015]. Recorded clinical measurements were quantitative. Data captured using health economic reports, and participant diaries produced both qualitative and quantitative data.

Health Economics

A health economic analysis at the individual patient level, and taking the NHS perspective, was conducted alongside the clinical study. The health economics investigated the proportion of therapists that completed and returned logs, the number of calls made and completeness of the calling records (relative to the maximum of 6 calls over the 12 week period), and the amount of therapist time shown as supporting children in the study. Mean amount of time spent by therapists during phone calls to the intervention group was calculated. The cost per child was estimated using validated national unit costs in the UK [Curtis and Burns 2015]], applied to recorded therapist time input. Data appertaining to the USG were examined but costs were not calculated

since this was the control condition and researcher contact was for the purposes of maintaining contact with participants in the trial, and not to provide therapeutic input.

Results

Feasibility RCT

Randomisation and Consent

Figure 1 shows the CONSORT chart for participant flow through the trial. Randomisation through minimisation was successful (see table 1). Minimisation achieved a balance between both groups, with only marginal imbalance between female versus male participants (20 and 33%). The majority of participants in USG used a project console (75%) which reduced to 57% in the SG (see table 3).

Insert figure 1 and table1here

More children were at GMFCS 2 (66%) than 1 (33%) participants. Forty-four children were assessed for eligibility. 14 were excluded as they were outside the acceptable age range, 1 child with GMFCS III was mistakenly approached by a clinical team. This child was offered a Wii Fit to take home and try, as they were upset when they realised they did not meet inclusion criteria. Five children declined to participate, 4 gave no further response on approach, and 1 was recruited/consented but not randomised due to a clinical decision that an upcoming operation placed the child outside the inclusion criteria, and that the study would be a complicating factor in post-operative recovery. Thirty individuals (68% of those approached) met the inclusion criteria and consented; but we are unclear how many throughout the region may have actually seen adverts/flyers for the trial out of a total GMFCS I-V estimated population of 300 children with CP.

Ten children in the SG (67%) and 11 in the USG (73%) completed the trial. There were a variety of reasons for dropout showing that this population group lead complex lives and are susceptible to a range of problems as many of these reasons were also found the amongst the general feedback of all children who completed the study: tiredness (3 children) was a factor causing dropout and a common reported reason for 'time off' from using the Wii Fit or following the programme. School was also a minor factor causing dropout but reflected through all children as after-school activities (1 child), and homework (1 child) were enough for some children to find the burden of the study too much to cope with. The final reasons were due either to surgery (1 child), or difficulties with using the technology where the balance board simply could not' read' when the child was standing on the balance board (1 child). For children with unilateral CP the balance board was frustrating as it was not reactive enough to the variant split in weight bearing between left and right side. Other children were also so light, due to age, and possibly lack of bone mineral density due to impaired weight-bearing, that the balance board did not find them when they were present on the board. Two children reported "no time" to carry out the activities. Lastly, one child with a comorbidity of autism could not adhere to the measurements and so left the study.

Willingness of clinicians and to recruit participants

PTs recruited most participants. Occupational therapists and Consultant Paediatricians also took part. Trial Physiotherapists worked on a casual basis which did not work effectively as other members of the research team became responsible for diary bookings.

Physiotherapists carrying out measurements

All therapists received a one day training package, but it was not possible – even with

the utilisation of a senior PT as part of the research team – to verify the true measure of the level and quality of advice provided. Variation in levels of experience, and across sites, was noted.

Insert table 2 and 3 here

Adherence to Programme

The SG completed a mean number of 19/36 sessions (56% adherence) whilst the USG completed 24/36 (66%). There were no adverse events. Children at GMFCS level II completed more sessions than GMFCS I (27 v 20), with higher mean subjective enjoyment rating of 3.1 v 2.1/5.

Feasibility of Study Measures

Overall, the measurement tools seem appropriate to VRT. The GMFM-66 was responsive to use but may have a possible ceiling effect as some children were high scoring throughout the study. Children at GMFCS II saw the most change in GMFM-66 score between baseline and week 12 in the SG, from 67.8 to 75 points (where the maximum is 100) on the scale whilst doing less activity overall than USG. Change in SG group was, on average, 6.2 points (75.2 to 81.7) whilst USG group experienced a change of 3.4 points, from 81.4 to 84.8, but began from a higher average baseline score

The Timed up and Go test (figure 6 below) showed equivalent score change across both groups. In seconds the SG group got quicker (6.2 to 5.5 seconds) as well as the USG group (6.4 to 5.3). The USG showed marginally more improvement. The test was easy to administer, although PTs did find that there was often variation between the style and height of equipment e.g. chairs or size of available rooms at CDCs. Equipment

403 that would be best standardised across clinical environments is in reality often lacking
404 uniformity, relying on therapists to make notes e.g. height of chairs, use of orthotics.
405 The BOT2 running speed and agility tool was inappropriate for widespread use
406 as the assessment required a lengthy running space simply not present in most CDCs.
407 However it must be noted that BOT2 is primarily used in children with Developmental
408 Coordination Disorder (DCD) and so this was the first attempt to use this tool with
409 ambulatory CP. Unfortunately applying BOT2 in a population that has impaired limb
410 mobility is difficult, as recording of dominant side only is advised. A future study may
411 look at positive change (if any) in the function of the impaired limb. BOT2 reports only
412 dominant limb change. BOT2 produced results showing that in the BOT2 short form SG
413 score increased from a mean of 46.5 to 52.3, compared to USG of 45.8 to 47.7 where
414 the maximum raw score is 88. This is a similar change to GMFM results. For the
415 balance subscale the difference in means was SG 19.9 to 24.1 and USG 22.4 to 25.1 a
416 change in mean score of 4.2 (SG) and 2.7 (USG). BOT2 can detect change but it is
417 problematic as to the amount of time taken to record all scores, and even with training,
418 PTs found the use of BOT2 tricky with children with CP, which may be due to lack of
419 familiarity with the tool where the trial was conducted.
420 The Goal attainment scale showed greatest improvement of all recorded scores,
421 as scores in SG showed substantial improvement of targeted outcomes from 35.2 to 54.9
422 or two out of three individualised targets successfully achieved. USG achieved similar
423 results from 37.6 to 58.8 or, more successful achievement of targets. As a result of the
424 feasibility RCT, therapists were so impressed with GAS that it was adopted in the local
425 community NHS trust. However, the GAS is less helpful as a measure of group changes
426 as it is designed to show change for each child individually against that child's
427 personally set goals, which are different for each child.

The Strengths and Difficulties Questionnaire (SDQ) was easy to administer with the parent often filling in the 16 point questions whilst other measurements were taking place. Change in children's strengths and difficulties were observed e.g. social interaction for example in SG 12.5 to 10.9, and USG 12.6 to 9.4. The parent completed SDQ showed both SQ and USG groups to be within the "close to average" category with symptoms marginally improving.

Insert table 4 and 5 here

Insert table 6 and 7 here

Physiotherapists suggested that the number of measurement tools was too many for the trial, as some children found the 1.5 to 2 hours taken to complete the measurements to be too long, especially where children had a co-morbid condition e.g. autism. For a future RCT measurement tools might need to be significantly streamlined to include those that measures that best detect change in motor function for children with CP and are easy to use without causing significant burden e.g. stress or anxiety to the child, family or therapist.

Insert table 8 here

Feasibility of Technology

The main issue with the use of a commercial console was in the presence of consoles already in many homes. However, 75% of participants used a project console, with data retrieved through SanDisk (SD) card and analysed, but with 25% electing to use a family owned console, which was lost data. SD data on the Wii fit is unreliable: it is unclear which user is active even when participants were given a pamphlet and talked through the creation of personal user profiles. The Wii fit cannot isolate the difference

between users except in querying weight change, but where children are close in weight (as happened with a family with twins) it is impossible to what was actually measured from Wii data. Without the purchase of SD cards being sent home, potentially invading home gaming privacy, this was lost data.

End of Project Survey

Positive comments were predominately reported with 40% more of comments in the supported group positive toward the programme. Activities were perceived as generally getting easier over time and strength of the intervention across both groups. There was variation in attitude toward difficulty of the games, and in achieving better game scores with some frustrated, others preferring challenge. This was equal across both groups. Families found the equipment set-up amenable, but the balance board (e.g. 5 year olds) was unable to detect weight of younger children especially those with hemiplegia.

Patient and Public Involvement

The design of the project logo was completed by the child of one of the parent advisers, who also took part in a pre-trial run through the intervention protocol to ensure the protocol was likely to be acceptable. Parent carer input was invaluable to the success and structure of the project, feeding ideas into documents and advice and future trials.

Health Economics

The children were monitored during the study by three therapists. Two therapists supported children in the intervention group (one supported nine children, the other four). The third therapist supervised all 15 children in the unsupported group. Logs were returned for 28 children, 13 (87%) in the supported group, 15 (100%) in the unsupported group. The health economist correctly guessed the group allocation of 21

of the 30 children randomised (75%).

Therapists' logs for the supported group (SG) showed a total of 54 calls (i.e. 4.2 per family) were made (69% of the maximum of 78). Of these 29 (54%) involved a conversation with a parent. The remainder of calls were not answered or went to voice mail, or in two cases parents stated they were too busy to speak. The mean time spent on phone calls for each child (including calls where there was no response) was 35 minutes, range 5 – 55 minutes.

For the unsupported group (USG), research fellows reported 74 calls (82.2% of the expected 90), 4.9 per family. Of these 40 (54.1%) were answered. The mean duration of calls per child was 12.6 minutes, range 2 – 20 minutes. In addition, the researcher sought advice from the supervising physiotherapist for three children whose parents raised particular issues about the use of the Wii. Total therapist time on these three enquiries was 45 minutes (5, 10 and 30 minutes respectively).

The cost of a therapist's time over the 12 week intervention was £20.10 per child in the supported group (A). This is based on an hourly rate for a band 5 physiotherapist (AfC specialist level) of £37 [44]. The physiotherapists in the study, however, were band 7 (advanced / team leader) and 8 (principal / consultant). Costs at these higher levels would be around £30 or £40 per child respectively.

Discussion

Our primary aim was the feasibility of a future multicentre RCT to test the effectiveness and cost effectiveness of a commercially available console for Virtual Reality for children with ambulatory CP in the home. Procedures attracted sufficient participants, children adhered to the recommended programme, measurement tools overall and

498 methods of analysis were appropriate, with some exceptions, and resource
499 implications/costs in relation to outcomes found that the staff cost was low. Our
500 findings are echoed in Levac et al [2017] who found that only active gaming home-use
501 groups showed significant improvement in GMFM scores when compared to clinic-
502 based programmes. Our work also follows Deutsch et al [2017] suggestion that research
503 looks primarily at prevention, participation and plasticity with our work here focusing
504 on understanding low-cost therapeutic participation in the home.

505 We calculated 95% confidence intervals of group differences for our five main
506 outcome measures, but the reliability of these requires possible use of data from other
507 studies to gain greater clarity of the sensitivity of these measures to detect appropriate
508 change as well as the potential utility of these measures in a definitive RCT.

509 We additionally wanted to investigate whether the treatment can be offered
510 through physiotherapy services in the NHS, which it could be. The treatment delivery
511 i.e. in the home had fair fidelity, but with the novelty of the games wearing off at about
512 the 7th week. 75% of participants used a project console, retrieved through SanDisk
513 (SD) card data and analysed, 25% elected to use family owned console, which was lost
514 data.

515 ***'Active Ingredients'***

516 One of the biggest issues surrounding the use of digital therapeutic intervention is the
517 identification of 'active ingredients' necessary for VRT to be useful to sustain impact.
518 Levac [2012] suggests that therapists should focus on gaining sustained engagement
519 over time with the whole family and child if therapy is to be carried out in the home.
520 Children and families should be given the opportunity to engage with their own therapy,

521 have autonomy over choices about activities, and be able to problem solve difficulties
522 [16]. Intrinsic and extrinsic motivational factors need to be emphasised so that
523 adherence is high, and outcomes are more likely to be successful. Levac suggests
524 therapists should develop their role carefully as a facilitator of the technology, by
525 selecting optimal games, monitoring progress (e.g. with Skype^{TM}), as attempted here,
526 with the assurance that there is clear alignment between daily activities and motor
527 outcomes that are important to the patient. One child who was part of this feasibility
528 study had a severe visual impairment, had extremely motivated parents and therapists
529 willing to make the study accessible for the child. A K-walker was used for the 12
530 weeks of the study, and the participant experienced a high change in score across 12
531 weeks. Children also experienced a waning of their interest in the 7th week, so
532 sustaining interest continues to be problematic. However, the deployment of engaged
533 therapists using focused and personalised scales in clinical conversations such as GAS,
534 making phone calls to individuals in lieu of clinical meetings, and asking participants to
535 keep diaries may help in engagement.

536 Van Hedel and Aurich [12] go even further than Levac and state that
537 rehabilitation technology should only be used with responsive patient groups, in which
538 case the identification of patient 'responsiveness' to VRT therefore becomes vitally
539 important. If motivation is related to adherence, which in turn is related to
540 responsiveness then exploring 'desires', interests, and enjoyment as part of
541 participation make VRT potentially as much about psychological attitudes surrounding
542 the technology as well as the actual improvements in motor function.

543 Levac points to therapists who measure client motivation in a standardised way
544 and can be replicated e.g. Tala et al's (2015) Paediatric Motivation Scale (PMOT) or the

O'Brien and Thomas (2010) User Engagement Scale, which in particular measures novelty and so captures the potential dropout of participants due to waning interest from technological innovation. Engaged learners are more likely to have improved outcomes, such as memory consolidation [16]. Thus, while VRT has potential for home-based use to augment therapy programmes, there is a need to consider factors influencing uptake and adherence to home-based applications.

Appropriateness of measures

SG was subjectively preferred from qualitative feedback, but participants preferred there to be more freedom to choose games, with potential for collaboration during play sessions.

Motor function was acceptably measured by GMFM-66. Measurement tools seemed appropriate to use alongside Virtual Reality Therapy. Timed Up and Go captured change, but with only marginal a difference between the two groups, so TUG may not be useful when detecting change with VRT. The BOT2 running speed and agility tool was inappropriate for widespread use as it required a lengthy running space which was not present in most Child Development Centres so that aspect was dropped. The short form and balance subscale detected change, given variation between groups, but was unfamiliar to PTs, and added to the time taken to complete measurements. The Goal Attainment Scale was successfully employed and in line with Levac [2012] and van Hedel and Aurich [2016] this seems sensible as the use of GAS involves a therapeutic discussion of motor strengths and weaknesses. One parent even pointed out that of all the tools, GAS enabled the parent and child to engage in a "body conversation" about those muscular areas of the body that were engaged during specific activity. SDQ was successfully used and revealed variation in children's capabilities

socially and emotionally across both groups so could be employed in a larger trial. The Edinburgh handedness inventory was useful when parents and children were unsure of the child's dominant hand, which must be complex given that neural pathways are hindered by a variant developmental trajectory than would otherwise have occurred without the lesion.

Physiotherapists suggested that too many measurements were used during the trial, with some children finding 1.5 to 2 hours of measurements a challenge, especially younger children or children with co-morbidity.

Limitations/Future adaptations

Treatment fidelity appears to be acceptable, however the novelty of the game-based therapy appears to have worn off by the 7th week, suggesting that, in a future trial, the duration of the intervention would be reduced from 12 to 7 weeks. Measurement tools would be streamlined to GMFM as the main outcome, with the addition of the GMFM challenge outcome module to overcome concerns of ceiling effect. GAS and Edinburgh Handedness inventory would also be effective in capturing variation in the therapeutic conversation as well as offer clarity over children's laterality. A future study would also benefit from the employment of a full time research therapist to enable self-direction during measuring, and organising a diary. Not being limited to a clinical environment, with additional clinical pressures could also enable a therapist to record change in a school or home environment or wherever is appropriate. Further, dedicated research PTs who have received training in delivering programme advice for SG would also have periodic inter-trainer reliability checks.

Adjuncts to therapy

Whatever the use of digital technology there is general agreement that it requires the use

of therapists or appropriate professionals to steer the direction of activity [12, 16, 20]. VR therapy therefore does suggest total automation of therapeutic choices which would replace human and clinical input.

Conclusion

Full Trial

A full trial appears feasible with adaptation to intervention, and use of other published material to estimate a sample size. The pooled standard deviation of GMFM-66 at baseline is approximately 12. To detect a 5 point difference between supported and unsupported groups, the effect size (Cohen's D) would be 5/12 =0.41 (i.e. medium). For 80% power at 5% significance, one would need 94 children in each group for the analysis. Allowing for attrition of 30% (by week 6), one would need to recruit 94/0.7 = 134 children to each group. It is also possible that with most drop outs being in children below 6 or over 12 years old, a focus on 6 to 12 year olds may well reduce attrition by 30%. By focusing on 6-12 age group attrition could be reduced enabling recruitment of 66 children.

Efficiency of analysis can be increased using analysis of covariance (ANCOVA). Assuming a correlation of 0.5 between baseline and follow-up GMFM, the required sample size becomes 71 in each group for the analysis and would require 102 children to be recruited per group accounting for attrition. This currently represents a total sample size of 204.

There is not enough data yet to make definitive comment on the usefulness of VRT as a successful therapy, although the trends seen in this study mirror most previous studies suggesting there may be potential improvement in motor function Positive change to

motor outcomes as a result of VRT will only be confirmed by a larger, sufficiently powered, study.

Therapeutic use of Nintendo Wii Fit in-home was inexpensive and acceptable in short periods of around six weeks. Further research is required to compare effectiveness with standard physiotherapy. Trials appear feasible, probably focusing on GMFM as the primary outcome.

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628 *Figure 1 Process of Informed Consent*

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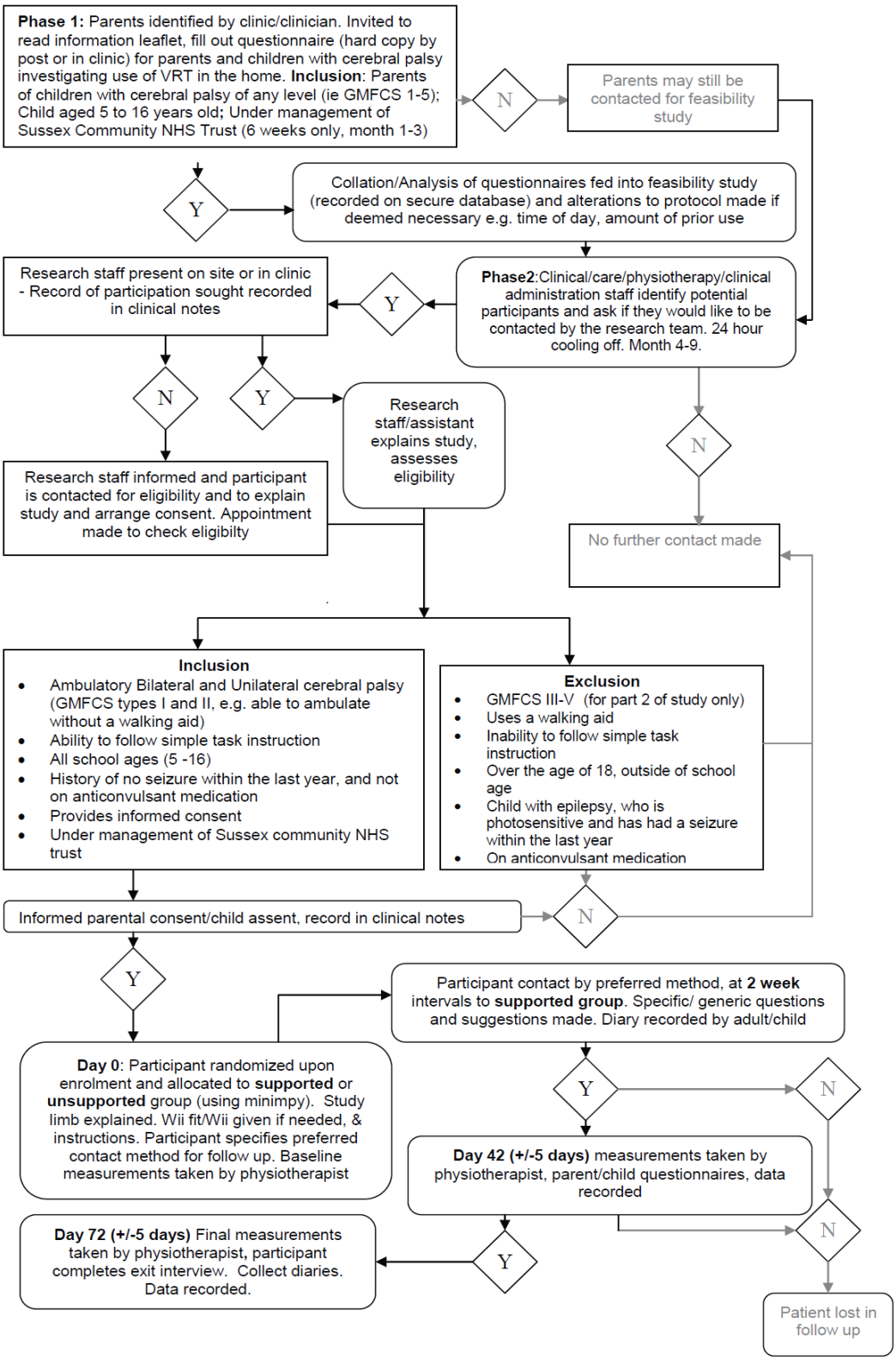

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632 *Figure 2 CONSORT Flow Diagram of Enrolment to Analysis*

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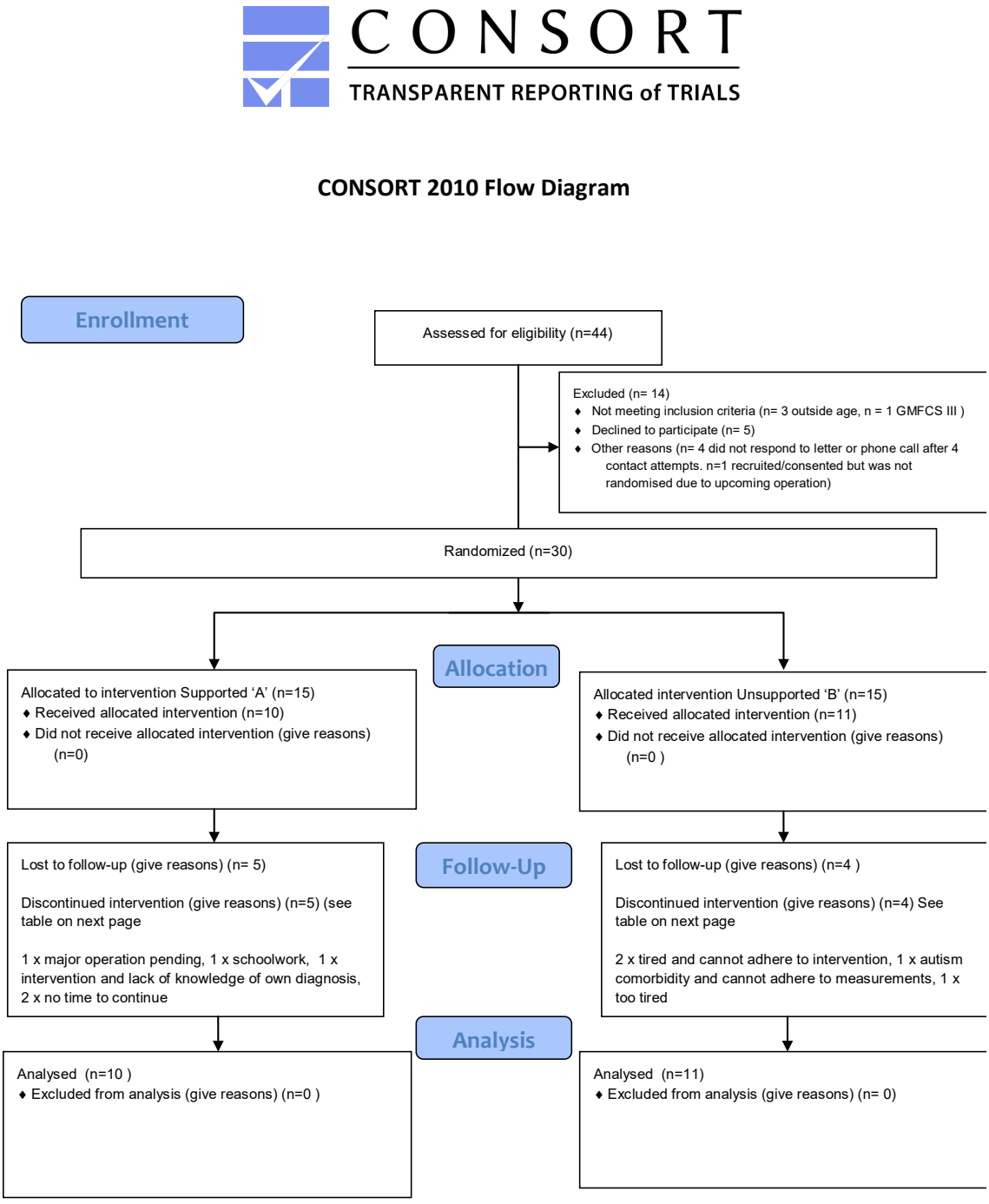

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639 *Table 1 Minimisation Balance*

	Supported		Unsupported	
	n = 15	%	n = 15	%
Female vs. Male	3	20	5	33
Secondary vs. Primary School Age	4	27	4	27
Bilateral vs. unilateral CP	5	33	5	33

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643 *Table 2 Characteristics of Participants*

	Supported		Unsupported	
	n = 15	%	n=14*	%
GMFCS 2 vs. 1	6	40	3	21
Left side dominant	7	47	5	43
Right side dominant	6	53	4	57
Neither side dominant	2	13	5	36
Left side affected	8	53	8	57
Right side affected	7	47	6	43

* data missing for one child

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647 *Table 3 Percentage of participants using project versus own console*

	Supported group		Unsupported group	
	n	%	n	%
Used project console	8	57	12	75
Used own console	6	43	4	25

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Table 4 Adherence to Intervention Schedule

	Supported group					Unsupported group					Difference	Bootstrap 95% C.I.* for difference in means
	n	mean	s.d.	median	IQR	n	mean	s.d.	median	IQR	in means	
Number of sessions	11	19	14.6	19	5 to 35	11	24	13.3	30	8 to 36	5	-7.1 to 15.4
Average rating	10	2.4	2	2.1	0.5 to 4.3	8	2.5	1.3	2.6	1.7 to 3.6	0.1	-1.7 to 1.4
Total minutes spent	10	819	634	633	333 to 1065	13	1230	1003	1148	324 to 1547	411	-196 to 1135

C.I.* bias-corrected and accelerated confidence interval

Table 5 Adherence to Intervention Schedule by GMFCS 1 and 2

	GMFCS 1					GMFCS 2				
	n	mean	s.d.	median	IQR	n	mean	s.d.	median	IQR
Number of sessions	16	19.2	13.8	20	6 to 33	6	27.7	13.3	34.5	24 to 35
Average rating	13	2.1	1.6	2.5	0.6 to 3.4	5	3.1	1.9	4	2.3 to 4.3

Table 6 Results for Gross Motor Function Measurement 66, Timed up and Go test, Goal Attainment Scale, Strengths and Difficulties Questionnaire

Outcome measure		Supported group					Unsupported group					Difference	Bootstrap 95% C.I.* for difference in means
		n	mean	s.d.	median	IQR	n	mean	s.d.	median	IQR	in means	
Gross Motor Function Measurement-66	baseline	15	75.2	11.1	72.6	68.9 to 79.1	15	81.4	13.1	84	69.6 to 89.7	-6.2	-14.4 to 3.3
	6 weeks	12	79.2	8.5	79.1	71.6 to 85.3	11	82.8	10.4	88	69.2 to 89.7	-3.6	-10.8 to 4.4
	12 weeks	10	81.7	8.4	82.5	73.1 to 88	11	84.8	10.1	83	71.7 to 92.1	-3	-10.6 to 4.5
Timed Up and Go test (in seconds)	baseline	15	6.2	1.6	5.7	4.8 to 8.0	14	6.6	1.8	6.4	5.9 to 6.9	-0.4	-1.8 to 0.7
	6 weeks	12	5.7	1.5	5.5	4.4 to 6.8	11	6.3	1.8	6.2	4.8 to 8.2	-0.6	-1.8 to 0.8
	12 weeks	10	5.5	1.5	5.3	4.1 to 6.5	11	5.7	1.8	5.3	4.3 to 6.0	-0.2	-1.6 to 1.2
Goal attainment scale	baseline	14	35.2	3.6	36.4	33.3 to 37.1	15	37.6	11.7	33.3	31.2 to 36.6	-2.4	-10.8 to 2.6
	12 weeks	10	54.9	15.5	55	40.3 to 63.9	11	58.8	7.1	56.7	52.7 to 63.5	-3.9	-13.8 to 7.5
Strengths and Difficulties Questionnaire	baseline	15	12.5	6.8	11	8 to 18	15	12.6	6.7	10	8 to 18	-0.1	-5.3 to 4.6
	6 weeks	13	9.5	7.4	9	4 to 14	11	9.8	3.5	10	7 to 12	-1.3	-3.0 to 0.3
	12 weeks	10	10.9	6.8	13	5 to 14	11	9.4	3.4	10	7 to 11	0.1	-1.2 to 1.3

C.I.* bias-corrected and accelerated confidence interval

Table 7 GMFM-66 results by GMFCS

Gross Motor Function Measurement-66 subgroups		Supported group					Unsupported group				
		n	mean	s.d.	median	IQR	n	mean	s.d.	median	IQR
GMFCS = 1	baseline	9	80.2	11.5	78.3	72.6 to 81.9	11	85.3	11.3	86.5	74.2 to 96
	6 weeks	7	83.6	8.1	84	79.1 to 86.5	8	86.6	8.1	89.7	84.5 to 89.7
	12 weeks	6	86.2	6.6	86.6	80.9 to 89.7	8	88.3	9	90.9	82.5 to 94.1
GMFCS = 2	baseline	6	67.8	4.6	69.7	64.6 to 70.4	3	73.3	15.3	76.8	56.6 to 86.5
	6 weeks	5	73	3.8	73.1	70 to 73.1	3	72.7	9.9	68.9	65.3 to 84
	12 weeks	4	75	6.1	72.9	71.5 to 78.6	3	75.3	6.7	71.7	71.2 to 83

Table 8 Results for Bruininks-Oseretsky Test of Motor Proficiency

Bruininks-Oseretsky Test		Dominant side										
		Supported group					Unsupported group				Difference	Bootstrap 95% C.I.* for difference in means
		n	mean	s.d.	median	IQR	n	mean	s.d.	median	IQR	in means	
BOT-2 short form	baseline	15	46.5	16.9	48	37 to 62	14	45.8	14.7	42.5	38 to 59	0.7	-12.3 to 10.8
	6 weeks	12	52.2	16.3	57.5	42.5 to 57.5	11	47.4	15.6	50	37 to 65	4.8	-7.7 to 16.7
	12 weeks	10	52.3	15.2	56	43 to 57	11	47.7	15.0	52	37 to 62	4.6	-9.2 to 16.1
Balance	baseline	15	19.9	9.6	17	14 to 29	14	22.4	9.3	25	16 to 29	-2.5	-8.6 to 4.9
	6 weeks	12	22.1	9.9	20	13 to 32	11	25.3	6.6	26	21 to 32	-3.2	-9.1 to 3.8
	12 weeks	10	24.1	10.1	26.5	19 to 32	11	25.1	8.3	29	22 to 31	-1	-8.4 to 6.9

C.I.* bias-corrected and accelerated confidence interval

Acknowledgements

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Appendix 1

Participant diary

Add here

Appendix 2

Intervention Strategy (supported group) – based on physiotherapist recommended games that focus on particular muscle groups and movement

Please note that it is important to stick to the following schedule and not allow your child to use any other games on the Wii Fit during their intervention sessions -

Remember every week consists of using the Wii Fit 3 times per week, for 30 minutes per session, and keep a record of how you're doing e.g. what levels are you on, or how fast are you getting?

Week	Game & Duration of play for that session	Believed physiotherapy benefit
1.	Penguin Tilt (15 minutes) Followed by Tilt Table (15 minutes)	Introductory session. Penguin Tilt: Good for all ages, core stability, side-to-side weight transfer. Tilt table: Core stability, side-to-side weight transfer, co-ordination
2	Ski Slalom (15 minutes) Followed by Football (15 minutes)	Maintaining previous weeks work on core stability and side-to-side weight transfer. Football: Side-to-side weight transfer, balance

3	Snowboard (15 minutes) Followed by Penguin Tilt (15 minutes)	This week whilst still fresh at the start of the session repeat snowboard which you may find challenging, and follow this up with Penguin Tilt from week 1
4	Free choice of the following games: Penguin tilt, Tilt table, Ski Slalom, Snowboard, Football, Balance Bubble. Each chosen game must be played for a minimum of 10 minutes.	This week you can choose any of the games you've been introduced to as a reward as you're halfway through the programme!
5	Ski Slalom (15 minutes) Followed by Tilt Table (15 minutes)	Ski Slalom: Core and quadriceps stability and strength, side-to-side weight transfer Tilt table: Core stability, side-to-side weight transfer, co-ordination
6	Balance Bubble (15 minutes) Followed by Tilt Table (15 minutes)	Balance Bubble: Side-to-side weight transfer, Core and quadriceps stability and strength Tilt table: Core stability, side-to-side weight transfer, co-ordination
7	Football (15 minutes) Followed by Snowboard (15 minutes)	Football: Side-to-side weight transfer, balance Snowboard: Core and quadriceps

		stability and strength, forward and back weight transfer
8	Free choice of the following games: Penguin tilt, Tilt table, Ski Slalom, Snowboard, Football, Balance Bubble. Each chosen game must be played for a minimum of 10 minutes.	This week you can choose any of the games you've been introduced to as a reward as you're halfway through the programme!
9	Football (15 minutes) Followed by Balance Bubble (15 minutes)	Football: Side-to-side weight transfer, balance Balance Bubble: Side-to-side weight transfer, Core and quadriceps stability and strength
10	Penguin Tilt (15 minutes) Followed by Balance Bubble (15 minutes)	Penguin Tilt: Good for all ages, core stability, side-to-side weight transfer Balance Bubble: Side-to-side weight transfer, Core and quadriceps stability and strength
11	Snowboard (15 minutes) Followed by Ski Slalom (15 minutes)	Snowboard: Core and quadriceps stability and strength, forward and back weight transfer Ski Slalom: Core and quadriceps stability and strength, side-to-side

		weight transfer
12	Free choice of all games -	This week you can choose any game from the Wii Fit including ones you've not played before as you've finished the programme.

Appendix 3: Specific Phone Call Question for Participants (every 2 weeks)

1. Did your child require any additional support whilst playing games e.g. holding someone's hand, having a chair in immediately in front of where you are playing?
2. Has your child needed additional support reading what is on the screen e.g. your child can follow instructions verbally but not on the screen?
3. Did your child need support during the 30-minute session i.e. not at the beginning or at the end of the session such as "what do I do now"?
4. How are doing with the games?
5. Do you think you are getting better with the games?
6. What level or times are you achieving?

Specific Phone Call Question For non-supported group (every 2 weeks)

How is it going?

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