

ORIGINAL REPORT

HOME-BASED COMPUTER-ASSISTED UPPER LIMB EXERCISE FOR YOUNG CHILDREN WITH CEREBRAL PALSY: A FEASIBILITY STUDY INVESTIGATING IMPACT ON MOTOR CONTROL AND FUNCTIONAL OUTCOME

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Objective: We developed a home-based rehabilitation exercise system incorporating a powered joystick linked to a computer game, to enable children with arm paresis to participate in independent home exercise. We investigated the feasibility and impact of using the system in the home setting.

Methods: Eighteen children with cerebral palsy (median age 7.5 years, age range 5–16 years) were recruited from local National Health Service and the exercise system was installed in their home for approximately 4 weeks. Baseline and post-intervention assessments were taken: Canadian Occupational Performance Measure (COPM); kinematic measurement of movement quality (indexed by duration and smoothness) measured using a motion tracking system when performing a standardized computer task.

Results: The system was used for a median time of 75 min (interquartile range (IQR) 17–271), equating to 606 outward and 734 inward movements. Pre-COPM, (median 4.2); post-COPM (median 6.0); obs=34; $z=3.62$, $p<0.01$). Kinematic analysis of pre- and post-intervention movements on the standardized task showed decreased duration and increased smoothness.

Conclusion: Some improvements in self-reported function and quality of movement are observed. This pilot study suggests that the system could be used to augment home-based arm exercise in an engaging way for children with cerebral palsy, although a controlled clinical trial is required to establish clinical efficacy. The feasibility of this technology has been demonstrated.

Key words: cerebral palsy; children; robotic.

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INTRODUCTION

Cerebral palsy (CP) is the commonest cause of severe physical disability in childhood in Europe affecting 2.1/1000 live birth

(1). An important feature in many children with CP is impairment of upper limb movements through weakness, spasticity, and loss of selective muscle activation. These impairments, in addition to sensory deficits, hinder the development of the smooth, coordinated movements required for activities of daily living. Studies using transcranial magnetic stimulation of the undamaged motor cortex of children with hemiplegic CP suggest that the facility for dissociated, coordinated, movement of the two hands may be severely attenuated (2). A child who experiences such difficulties is naturally reluctant to use the paretic limb, leading to further restrictions in the child's exploratory learning, acquisition of basic manual skills, personal independence, education and play.

An important component of upper limb "habilitation" programmes for children with CP is the practice of exercises based on useful movements, such as reaching (3). These movements are usually assisted by a physiotherapist or occupational therapist, providing a combination of motive power (to supplement muscle weakness) and guidance (to correct the inappropriate movement that results from poor coordination). The degree of improvement resulting from these exercises depends on the amount of appropriate practice undertaken. This is attested by the effectiveness of "constraint therapy", which obliges children to use the paretic arm in some daily tasks by restraining the other arm: the increased amount of practice appears to be an important component of this approach (4). Other treatment modalities, such as orthotics (5, 6), botulinum toxin (type A) (7, 8) and electrical stimulation (functional or sensory) (9, 10), have been suggested as useful interventions to improve hand and arm function. A common adjunct to all these interventions is the recommendation that children are encouraged to practice appropriate arm exercises.

Current methods of undertaking upper limb exercise are principally limited in the amount of appropriate exercise that can be undertaken. Exercises assisted by a therapist are inevitably labour intensive and therefore resource-limited. Although constraint therapy can be employed at home, it does not assist the child to achieve appropriate movements, and compliance with the constraining protocol can be difficult (11). From the child's perspective, formal exercises are often unexciting; it is therefore difficult to maintain enthusiasm in the absence of

the therapist. For these reasons, there is growing interest in technologies that offer the possibility of providing programmes of simpler exercises for children to pursue independently, releasing physical and occupational therapy time to focus on other complex treatments. The use of technology to engage children with CP in rewarding activities is not new. Various devices already enable children to engage in perceptual motor exercises despite upper limb impairment, such as a “furry toy” operated by the voice or body movement (12), a robotic arm operated by push buttons/laser pointers/head switches (13) and a musical instrument operated through a unique control panel (14). The technological approaches cited above have demonstrated the willingness and enthusiasm of children with disability to engage with technology. However children with CP with limited voluntary movement may have great difficulty in engaging with these devices, which often require a reasonable degree of voluntary arm movement. None of these technologies physically assists the child in undertaking appropriate exercises. To address this need we developed and evaluated a powered joystick system linked to a computer exercise workspace that provided controlled guidance to the child’s arm to enable him or her to undertake the exercises (15). A key aspect of this home exercise device that differentiates it from a simple computer gaming system is the controlled physical assistance provided by the powered joystick. In this way children with poor voluntary arm movement can be physically guided during the exercises as required, in a motivating and fun way.

The aims of this study were: (i) to determine the feasibility of using a computer-assisted arm exercise system for children with CP within the home environment; and (ii) to assess the effect of its use on quality of arm movement and function.

METHODS

Participants

A total of 18 children with CP were recruited. All children had upper limb impairments that affected their ability to use the arm and hand in day-to-day tasks. The treatment was performed in the children’s homes.

Study design

AB design with pre- and post-intervention assessments (within one week of completing the intervention period).

Device specification

The home use rehabilitation device was developed in two versions through a user-centred design process involving the children and their parents (15–17). Two device versions were built, essentially performing the same tasks and providing the same guidance: (a) a Planar Space Assistive Movement Device (PSAMD) (Fig. 1a) and (b) a Restricted Space Assistive Movement Device (RSAMD) (Fig. 1b). Both devices were adjustable to suit the individual children’s range of upper limb movement and ability to grasp, but had different device footprints. The PSAMD was developed offering a greater level of assisted upper limb movement, supporting the child’s arm in the transverse plane, but had a larger footprint. The RSAMD was developed to suit a more restricted home environment space, but with a smaller maximum level of assistance. Both devices had a footprint that was deployable in the home environment and provided assisted therapeutic exercise for children. Ten exercise devices were constructed, 5 of each type, for clinical evaluation. Software was developed for use with the device to provide the gaming exercise environment. The gaming environment was developed with feedback from children. Five different themed games were developed: (i) a spaceship game; (ii) a monkey chasing bananas game; (iii) a helicopter and balloon game; (iv) a shark game; and (v) a football game. All of the games, independent of the theme, encouraged the users to perform aiming movements in the transverse plane, with the joystick system offering limb support. Users were given instructions to complete the movements as quickly, but as accurately, as possible. The software was written in visual C++ in the .NET framework and designed to be compatible with standard home personal computers (PCs). The software encompasses both the computer game and the control algorithm, which determines physical assistance given by the joystick (PSAMD and RSAMD) to the child. Software control used a proportional, derivative algorithm with a sigmoid ramping function. Implementation of the sigmoid ramping function, to alleviate jerk, was in response to feedback from children. This controller allowed the hardware to be adjusted for the needs of an individual child based on clinical assessment by an experienced paediatric physiotherapist.

Exercise regime

The version of the home-based rehabilitation system (HB-RES) was chosen by the child and their parents with advice from the paediatric physiotherapist. The level of assistance provided by the system was determined by the paediatric physiotherapist. The level set was such

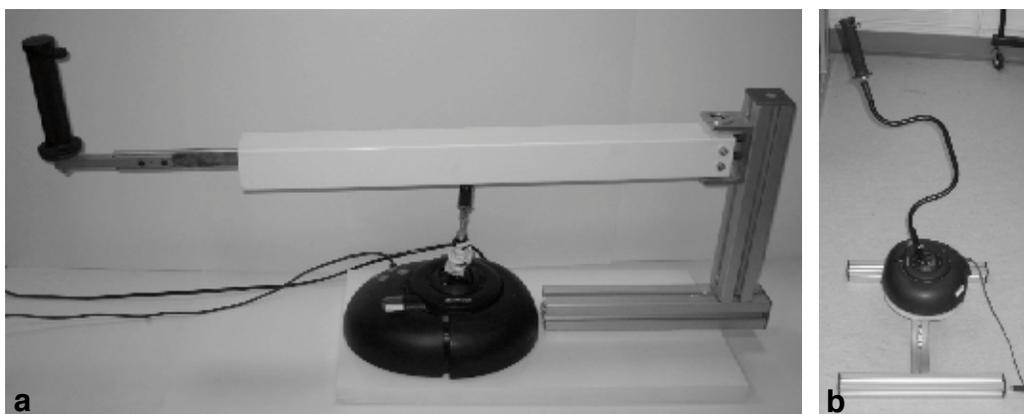


Fig. 1. (a) The Planar Space Assistive Movement Device. (b) The optimized Restricted Space Assistive Movement Device.

that the child had to use their upper limb as much as possible (that is the child was not “passive” whilst the joystick provided full assistance) for all the arm exercises required. The system was delivered and set up in their home by one of the research team within 1 week after the baseline assessments. Each device was loaned to the child for 4 weeks. Regular telephone checks were conducted by the research team to ensure that the system was working. The children were instructed to use the system as much as they wanted over the 4 weeks (i.e. unrestricted use). One member of the research team visited the home after 2 weeks to review the initial parameter settings and to change them if necessary. The duration and type of exercise practice undertaken at home was recorded by the HB-RES software. This was the quantitative indicator of enthusiasm with which this equipment is used at home.

Outcome measures: device usage

Every time the child played the game a static data-file within the HB-RES data capture software was appended. These data were used to quantify game usage and performance: (i) total time played on the device; (ii) total number of inwards and outwards movements; and (iii) total number of times the system was used.

Outcome measures: functional measurement

The Canadian Occupational Performance Measure (COPM) (18) was used as a standardized child-centred measure designed to detect change in a person’s self-perception of occupational performance over time. In interviews with the parents and children, this tool allowed several issues with which the children had difficulty to be identified. Three broad areas of daily activity were identified: (i) personal care (e.g. dressing, hygiene), (ii) productivity (e.g. play/school – play skills, homework); and (iii) leisure (e.g. recreation – hobbies, crafts, reading). Each activity identified by the parents and/or child is scored out of 10 for importance by the parents in order to prioritize the problems (1 being the most important). The 5 most important issues were then scored out of 10 by the parents to capture their opinion about their child’s competency at the task. A summary score was derived following guidance provided in the COPM manual. Change scores between pre- and post-intervention assessment were calculated. The manual dexterity section of the Movement Assessment Battery for Children (MABC) (19) was used to classify the child’s baseline abilities. MABC is an assessment of motor skill tool in which there are 4 age groups with differing tasks. The scoring depends on the numbers of errors made during the task. Scores are marked according to times taken to achieve a task taking account of errors made in completing a task (range 0 (the best) to 5 (worst) for each task). Children from a higher age group who were unable to complete their age group dexterity tests used items designed for a lower age group to allow measurement of hand function.

Outcome measures: kinematic measurement

The pre- and post-intervention measurements of voluntary arm movement were standardized using a predefined HB-RES exercise task. The task required each child to attempt equal amplitude arm movements (3 movements away from the body and 2 movements towards the body) using standardized target sizes. Each child was asked to repeat the exercise 5 times. Kinematic measurement of voluntary upper limb movement was recorded during these exercises using an Optotrak Certus movement recording system. Infra-red emitting diodes (IREDS) were attached to the child’s paretic limb in the configuration illustrated in Fig. 2. Data were collected at 100 Hz, and analysed using Labview (version 8) customized software routines. The data were filtered using a dual-pass Butterworth second-order filter with a cut-off frequency of 16 Hz (equivalent to a fourth-order zero phase lag filter of 10 Hz) and the tangential speed of the markers was computed. These data were used to determine the onset and offset of the movement using a standard algorithm (threshold for movement onset and offset was 5 cm/s). The onset was taken as the earliest time at which movement occurred. The offset was taken at the time at which the target was contacted. The solid body marker system was used to determine vol-

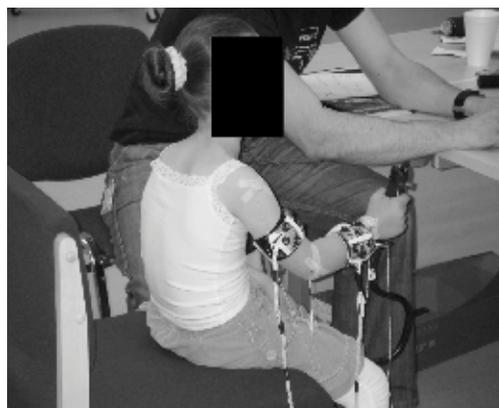


Fig. 2. The infra-red marker placement for upper limb kinematic measurement.

untary elbow flexion and extension. Quality of voluntary movement was assessed using total movement time (MT_t), peak speed (PS) and smoothness of movement (normalised average rectified jerk (NARJ)) (20) as these are known to be reliable indices of skilled performance (shorter MT and higher PS and lower jerk indexes higher performance levels). The range of elbow (angular) movement was also analysed as a marker of range of voluntary movement.

Ethics

The study was approved by the UK Leeds Research Ethics Committee (ethics approval number 03/162). Informed written consent was obtained from all parents and assent from children.

Statistical analysis

Descriptive statistics are used to report for how long and how many exercises were undertaken by children while using the HB-RES system at home. Non-parametric statistics (Wilcoxon test) were used to analyse pre- and post-intervention changes in the COPM score and all kinematic variables (i.e. movement time, peak speed, time to peak speed, movement jerkiness (NARJ), range of elbow movement). For each child, the median value of the repeated measurements per condition of the variables of interest was used in statistical analyses with α set at 0.01 to account for multiple pair-wise comparisons.

RESULTS

Of the 18 children recruited one did not attend the post-intervention assessments. Eighteen children (age range 5–16 years, median 7.5 years; 13 male) completed the 4-week programme using the home-based exercise systems. Fourteen children had predominantly right arm paresis. Six of the 18 children were wheelchair users. The children recruited to the study had significant age-adjusted upper limb movement impairments, as identified by the MABC. At baseline all 18 children scored MABC grade 5, which is the lowest functional MABC grade. The MABC tasks were beyond the ability of most of the children and this, combined with the scoring system, demonstrated a limiting effect with the MABC as a measure of fine motor control with this population. The post-intervention reassessment indicated that all children scored MABC grade 5. During the course of the 4-week study all children continued with their existing rehabilitation treatments.

Home usage

Eighteen children used the HB-RES over a period of 4 weeks (median total time 75 min; range 0.2–271 min). They practised a median of 606 outward movements (range 4–1684) and a median of 734 inward movements (range 5–2041). Two children used HB-RES for less than 30 min over the 4-week period. Five children used the system for up to 6 weeks because of intervening holiday periods.

Functional outcome

At baseline, parents and children identified a range of day-to-day tasks that were difficult or not possible to perform independently (e.g. using affected arm to pick up things, dressing, using zips, adjusting clothing, etc.). Improvement in some of these personal activities of daily living occurred following intervention. COPM scores were not available on one child. The individual COPM scores are shown in Table I. The pre-intervention COPM median score across the group was 4.2 (range 1.0–5.6) and the post-intervention COPM median score across the group was 6.0 (range 4.4–7.4; $p < 0.01$) (Table II).

Voluntary upper limb movement

The kinematic measurement system data for 2 of the 18 children was not analysed, as one child did not attend the post-intervention measurement system, and for the second child the measurement system was not able to track the arm movement with sufficient reliability to allow the data to be analysed. Kinematic data for 16 children were available for analysis. The MT_p , PS and movement jerkiness (NARJ) improved both in the outward and inward components of the standardized tasks (Table II). No significant change in range of elbow movement was identified. There was no difference in functional outcomes between the two versions of the home exercise system that were selected by the parent and child.

Table I. Pre- and post-intervention individual child Canadian Occupational Performance Measure (COPM) scores

Child ID	Initial COPM score	Final COPM score	Change in COPM
1	4.2	7	2.8
2	4.2	5.6	1.4
3	–	–	–
4	5.2	7.2	2
5	5.2	7.4	2.2
6	5.6	6.6	1
7	4.4	6	1.6
8	3.5	5.5	2
9	3.6	5.8	2.2
10	3	7.4	4.4
11	2.2	4.4	2.2
12	4	6.5	2.5
13	3.6	7.4	3.8
14	4.6	6.4	1.8
15	3.6	4.4	0.8
16	5	6	1
17	1	5	4
18	4.3	5	0.7

ID: identification.

Table II. Summary of functional and kinematic outcomes

	Pre-intervention Median (range)	Post-intervention Median (range)
Function		
Canadian Occupational Performance Measure (COPM)	4.2 (1–5.6)	6.0 (4.4–7.4)*
Quality of reaching movements		
Movement time (s)	3.05 (1.5–8.3)	1.7 (1.2–5.5)*
Peak speed (mm/s)	408 (132–754)	727 (251–1065)*
Time to peak speed (s)	0.55 (0.4–1.1)	0.5 (0.3–2.9)
Movement jerkiness (NARJ unit)	29,889 (7289–254,190)	8149 (4077–89,716)*
Elbow range of movement (o)	33 (7–117)	49 (13–80)
Quality of retrieve movements		
Movement time (s)	3.05 (1.5–8.8)	2.3 (1.1–5.6)*
Peak speed (mm/s)	351 (129–694)	585 (270–808)*
Time to peak speed (s)	0.7 (0.4–3.3)	0.6 (0.3–4.1)
Movement jerkiness (NARJ unit)	48,438 (5091–563,123)	16,190 (3393–85,903)*
Elbow range of movement (o)	34 (5–86)	32 (15–78)

* $p < 0.01$. COPM: Canadian Occupational Performance Measure; NARJ: normalised average rectified jerk.

DISCUSSION

The use of robotic systems to assist adults with arm function impairment (e.g. caused by stroke) is now being considered by a number of research groups, although few are working with children who have CP. Linking robot-assisted exercise to simulated computer game interfaces may be useful for maintaining interest throughout the exercise session (21) and improving motivation (22), with potential for better outcomes. If this approach is to be successful in children, the playability of the computer-generated exercise environment also needs to be considered. Even with rudimentary gaming we have shown that children can be assisted to undertake home exercises in a controlled therapeutic manner. Our study has shown that it is possible to engage children in assisted home exercise at home. Despite children being asked to use the device whenever they wanted to, the median total time used over 4 weeks was 75 min, with 14 out of 18 children using the system for more than 30 min, and 5 using it for more than 2 h. The exercise system allowed the therapist to tailor the exercises to the abilities of the child (i.e. personalized exercise), which could be changed as the child improved. Clearly it is possible that the improvements in kinematic variables might be related just to children becoming better at playing the exercise game. However, the concurrent improvement in function would suggest that improvements in quality of voluntary movement occur despite these children having moderate-to-severe upper limb impairment at baseline (as defined by the MABC). This translated into improvement in specific goals set by the parents and child prior to intervention using the COPM method. Children with visual impairments and mobility impairments were able to use the system at home. The system required little support from engineers once installed at home. Home visits were mainly to adjust the task difficulties as the children undertook the computer-generated exercises. Children and parents were interested in the use of assisted movement and gaming environments as a method of encouraging therapeutic home exercise within the

therapist's treatment plan. These concur with other reports in the use of computer games for children with CP (23, 24). Akhutina (25) et al. tested 3 different representations of a specific test with children with CP. Their results showed that the use of a "virtual" environment has a positive effect on the child's spatial awareness; coupled with more traditional tabletop games these systems offer improvements in overall functioning.

Despite the generally positive outcome of this study, there were a number of important limitations that need to be addressed in future studies: (i) the lack of a control group limits conclusions about the effectiveness of the device, as it is not possible to determine the "placebo" effect of the intervention (children ID 10, 11 and 14 showed improvements in the COPM, but only performed less than 30 reaching exercises during the 4-week period); (ii) the children also used the HB-RES system for differing amounts of time; there was no relationship between how long the device was used and outcome in terms of kinematic variables or functional outcomes, thus it is difficult to identify the mechanism of improvement; (iii) this was a short-term study with the effects of the intervention measured at the end of the 4-week treatment period, and therefore there is no information about long-term effect. Some children reported that they did not use the system towards the end of the 4-week period as the games became repetitive and therefore less motivating.

In conclusion, this study suggests that disabled children with significant upper limb impairments can use exercise systems that assist/guide arm movement in the context of practicing functionally relevant movements. This open-label feasibility study indicates the potential impact of device-based home exercises in terms of short-term functional gains. Further work is required to improve the motivational nature of the exercise workspace and to determine the efficacy of the intervention in randomized controlled trials with appropriate attention control comparator intervention. However, the feasibility of such technology has been demonstrated.

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