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Abstract: Feasibility of school-based computer-assisted robotic gaming technology for upper limb rehabilitation of children with cerebral palsy.

Introduction

We investigated the feasibility of using Computer-Assisted Arm Rehabilitation computer games in schools. Outcomes were children's preference for single player or dual player mode, and changes in arm activity and kinematics.

Method

Nine boys and two girls with cerebral palsy (6 – 12 years, mean 9 years) played assistive technology computer games in single-user mode or with school friends in an AB-BA design. Preference was determined by recording the time spent playing each mode and by qualitative feedback. We used the ABILHAND-kids and Canadian Occupational Performance Measure to evaluate activity limitation, and a portable laptop-based device to capture arm kinematics.

Results

No difference was recorded between single-user and dual-user modes (median daily use 9.27 versus 11.2 minutes, $p = 0.214$). Children reported dual-user mode was preferable.
There were no changes in activity limitation (ABILHAND-kids, $p = 0.424$; COPM, $p = 0.484$) but we found significant improvements in hand speed ($p = 0.028$), smoothness ($p = 0.005$) and accuracy ($p = 0.007$)

Conclusion

School timetables prohibit extensive use of rehabilitation technology but there is potential for its short-term use to supplement a rehabilitation programme. The restricted access to the rehabilitation games was sufficient to improve arm kinematics but not arm activity.

Keywords: cerebral palsy; children; robotics; assistive technology; computer games

Introduction

Cerebral palsy (CP) is a relatively prevalent neurological disorder in children, occurring in 2.08/1000 live births [1]. Impairment of upper limb movements, characterized by increased duration, reduced peak velocity, increased variability and less straight hand trajectories [2-4], is present in up to 80% of children with cerebral palsy. Upper limb difficulties cause activity limitation for children with cerebral palsy, activity being defined as the execution of a task or action by an individual [6]. Physiotherapy and occupational therapy aim to reduce activity limitation and maximise participation in life situations, including using techniques such as repetitive reaching to retrain the brain and improve motor skills [7,8]. Although little research exists to indicate the quantity of intervention necessary for functional benefits in children with cerebral palsy, 20 - 45 minutes three times a week [9], or 75 minutes three times a week [10] produces observable improvements that can be evaluated using objective validated measures of upper limb activity. This requires a considerable time commitment for therapists, for whom visiting every child on their caseload even once a week is a challenge.

This has led to innovative approaches which aim to supplement rehabilitation by encouraging more intensive repetitive use of the affected upper limb, and which can be undertaken in a variety of settings e.g. home, school and clinical settings. For example, Constraint Induced Movement Therapy (CIMT) is an experimental approach [11] to supplement therapy programmes by constraining the affected limb, encouraging increased and more intensive practice of useful activities. CIMT has produced promising results in small trials [11,12]. Similarly, the potential for the use of robots to support repetitive motor training as an adjunct to therapy-supported programmes for motor rehabilitation [13] has provided impetus into the use of robotic assistive technology to supplement exercise programmes of children with cerebral palsy through assisted repetitive reaching [14,15].

The aim of robotic computer-assisted robotic rehabilitation equipment is to encourage children to exercise in a therapeutic way - for example, through repetitive reaching movements - that children find fun and that has a positive effect on activity limitation. Computer-Assisted Arm Rehabilitation (CAAR) games proved feasible in the home setting, and indicated the potential for kinematic and activity limitation improvement [15]. Prompted by the findings of this feasibility study [15] and our user group meetings [16,17] a purpose built system was designed and implemented. Firstly, some children preferred to have the option of playing with friends and family in competitive or collaborative games; and secondly, the assistance provided by the prototype version of the gaming joystick was not sufficient for a child with an arm that had a greater degree of impaired movement or spasticity. We also visited schools to look at the environment and held a number of interviews with teachers, teaching assistants, therapists and children [17]. This resulted in production of a bespoke mobile dual-user CAAR games system (see figure 1).

Figure 1. The Computer Assisted Arm Rehabilitation (CAAR) games system. Two adjustable height powered robotic joysticks and associated hardware are housed in a portable trolley system. The bi-manual switch and emergency stop are illustrated.

The games are played using an assistive robotic arm which incorporates motors powerful enough to provide adequate assistance to a child with restricted arm movements. The games are a combination of non-resting and resting games (children take turns) and co-operative and competitive games. An additional benefit of this dual-user system is that it increases social integration of disabled children in schools, stated goals of government educational and child welfare policy [18,19].

This paper presents the feasibility of deploying the CAAR games system to English schools for the purposes of engaging children with cerebral palsy aged 5 – 12 years old in daily arm rehabilitation exercises during the school week. The primary aim of this study is to establish whether children play the games system more if they used the system in collaborative mode (playing with school friends) or in independent mode (playing by themselves). This by implication indicates which mode directs the child to undertake more rehabilitation, increasing the benefit for greater improvement in activity limitation and arm kinematics. The secondary aims of the study are: 1) to evaluate whether arm activity improved as a result of use of the CAAR games system; 2) to evaluate whether the arm kinematics improved as a result of use of the CAAR games system; and 3) to determine the feasibility of deploying the CAAR system into the child's school and using the CAAR within the constraints of the school timetable. Holt et al [17] describe the games system, its development and the games themselves in more detail, and gives a full account of the success of the system's integration into the school timetable.

Method

Participants

Children eligible for the study were identified through local paediatricians and occupational therapist teams. Inclusion criteria were children with cerebral palsy aged between 5 and 12 years old, who had upper limb activity limitation and cognitive ability to understand and play simple computer games. Twelve children with cerebral palsy were identified and agreed to take part in the study but one withdrew when the school (a secondary school) refused to participate because of the intensity of their curriculum. Eleven children in nine schools (eight primary schools and one senior school) therefore took part in this study (eight boys, three girls, all with unilateral impairment but for one child with bilateral involvement, aged from 6 to 12 years old (mean age 9 years, SD 1 year 11 months)).

Study design

The study was a cross-over design (AB-BA), where Group A played with school friends (dual-user mode) and Group B played by themselves (single-user mode). Each group played the games for four weeks at a time, each separated by a minimum of three weeks 'wash-out' period. The wash out period was by necessity timed to include school holidays. We included a period of CAAR system maintenance between deployments, therefore each deployment of the CAAR games system took at least 12 weeks: two four-week deployments separated by a three-week wash-out period, and one week of maintenance. One deployment used the six-week summer holidays as the wash-out period, extending the length of the deployment to 15 weeks including the week of maintenance. For the dual-user mode, children selected up to four non-disabled friends from their school with whom to play. Only one parent refused consent for their child's participation, believing erroneously that this meant missing lessons.

With four two-user systems and 11 children, there were three deployments:

- Deployment 1: four games systems, used by five children in four schools. These five children, and those in each of the other phases, were not allocated randomly to the first deployment but were selected because of the geographical proximity of their schools for efficiency of technical support and delivery/collection of the CAAR devices.
- Deployment 2: three games systems, used by three children in three schools.
- Deployment 3: two games systems, used by three children in two schools.

Children were randomly allocated to play dual-user or single-user use in each deployment.

Device specification

The system comprises of two main parts: i) the hardware and ii) the software, which together combine to make the CAAR games system.

Hardware (see figure 1)

The hardware allows the child to physically interact with the exercise system in a safe and controlled manner. It enables bimanual operation in which the child's paretic or more affected arm controls the movement of an icon on a computer screen, while the least affected or unaffected hand is used to operate a hand held push-button switch to further interact with the system. The child controls the position of the screen sprite (the game's moveable character) with the robotic arm which applies assistive forces based on the distance to the target and the level of assistance. The level of assistance is set depending on the level of impairment assessed by a research physiotherapist (NP) and changed by an Adaption-to-Player-Performance Algorithm (APPA) within the CAAR system software. The hardware, including the computer and screen, is mounted on and within a single trolley, designed to be portable within a school, that can be moved to a convenient location then secured in an appropriate position (see figure 1). A key element of the system was 'plug and play' (identified through the User Centred Design process [17]): the CAAR system can be switched on, initialised and played within minutes.

Software

The software creates a graphical environment in which the child moves an on-screen sprite to complete tasks of varying levels of challenge. At the start of each session an assessment task calculates appropriate assistance levels to be delivered by the handle for the session, within appropriate limits. These limits are automatically adjusted based on the child's movement performance, measured over a number of sessions and initial guidance provided by a therapist. Feedback is provided to the child through on-screen scores which are updated in real-time. The software keeps a history of usage and scores for the child, which can be used later for further analysis.

Exercise regime

We asked that schools achieved 30 minutes of use a day, not necessarily in one games session. Other than to encourage school staff to allow access to the system whenever it was appropriate within the school timetable, we tried to avoid being too prescriptive about use. Any other rehabilitation programmes were to continue as detailed by the child's physiotherapist or occupational therapist.

Outcome measures: device usage

On each occasion that a child played the game system, the games system recorded details of which games were played, the amount of time played, and recorded performance statistics.

Outcome measures: functional measurement

Functional performance of the arm was evaluated using two measures: the ABILHAND-kids [20] and the Canadian Occupational Performance Measure (COPM) [21]. Assessments took place at each child's home at five time points:

1. Time point 1: two – four weeks before the child began using the games system (a Control assessment);
2. Time point 2: Baseline assessment, within three days of the child beginning the first four week deployment;
3. Time point 3: within three days of the child completing the first four week deployment;
4. Time point 4: within three days of the child beginning the second four week deployment;
5. Time point 5: Final assessment, within three days of the child completing the second four week deployment.

ABILHAND-kids

The ABILHAND-kids was developed specifically to measure manual ability (defined as “the capacity to manage daily activities requiring the use of the upper limbs”) of children with cerebral palsy aged 6 – 15 years old [20]. The ABILHAND-kids is reported as having strong psychometric properties for assessing manual ability in this population [22]. The ABILHAND-kids produces ordinal outcome scores that can be transformed to linear (interval) measurement.

Canadian Occupational Performance Measure (COPM)

The COPM involves the formulation of personalised functional goals in a semi-structured interview with parents (or with the older child) [21]. Outcome goals are therefore not standard but individualised for each child. The COPM is known to be a responsive measure [21,23] although there are psychometric shortfalls with its scoring and suitability for its use in statistical analyses [24]. Parents rate the child’s performance out of ten for each of the personalised goals, and also their satisfaction for the level of performance. We present outcome scores for performance only. A clinically significant change is interpreted as a change in outcome score of 2.0 or more.

Outcome measures: kinematic measurement

Our previous feasibility study for a home-based Computer-Assisted Arm Rehabilitation system [15] evaluated upper limb kinematics using a laboratory-based motion capture infra-red optical tracking system to capture arm movements. We felt that it was unreasonable to ask families to travel on five occasions to the University of Leeds laboratory for kinematic analyses. We instead adapted a portable kinematic assessment tool called Clinical Kinematic Assessment Tool (CKAT) [25]. The CKAT has been developed using non-disabled adults using a tablet [25] but was adapted to use the home-based feasibility study joystick [15] on a laptop. CKAT captures spatiotemporal movements of the upper limb by recording movement parameters (defined in table 1) of the screen cursor (sprite) as the child undertakes a number of computer-based tasks using the adapted joystick. Tasks are shown in figure 2 and consist of practice, speed, tracking and tracing tasks that attempt to mimic paper-based hand-control assessments [25]:

Practice/warm up. Two practice sessions to accustomise the child to use of the joystick and control of the cursor movements consisting of tracing two shapes (a house followed by a tree).

Aiming task: Pentagram. The aiming task consists of two attempts at a series of aiming movements around a Pentagram shape (see figure 2), guided by a target that moves with each successful aiming motion from point-to-point. The kinematic parameters measured by CKAT in the aiming task are Path Length (distance travelled by the screen cursor for each point-to-point movement), Path Length Time (time taken to travel each point-to-point movement) and smoothness of each point-to-point movement.

Tracking task: Figure of 8. Four timed tracking tasks: the children track as closely as possible a target circle moving in a horizontally-positioned Figure of 8 (see figure 2). The first two tasks are at a slow speed and the second two at a fast speed; each task lasts 31 seconds. Speed of the task is pre-determined and fixed. Children are asked to match the speed and position of the green circle.

Tracing task. Four untimed tracing tasks (identical shape, rotated 90° each time, see figure 2). There is no time limit; children are asked to take their time and to trace the shapes as accurately as possible.

Table 1. Kinematic Parameters [25]

Figure 2. The CKAT system. Left: illustrates the large range of motion passive joystick and laptop computer which implements the software programme tasks. Right: The CKAT tasks which the child performs using the system on the left a) practice tracing, b) pentagram, c) figure of 8, d) untimed tracing.

Outcome measures: qualitative evaluation

The children and school staff that were involved with the games system were asked to complete a short questionnaire. The questionnaire aimed to find school staff's views on the suitability of the games system within the school environment and for its use within the schools' timetables. The children were asked to nominate their favourite games, their favourite mode of playing and to comment on how they would improve the games system.

Ethics

Favourable ethical opinion was obtained from Leeds (West) Research Ethics Committee (REC ref: 09/H1307/48).

Statistical analysis

To determine whether children played the games system more in single-user mode (playing by themselves) or in dual-user mode (playing with school friends), we used the non-parametric Wilcoxon Signed Ranks Test with alpha set at 5%.

To determine whether any changes in activity took place that could be attributed to the games system, we used the non-parametric Wilcoxon Signed Ranks Test with alpha set at 5%. Activity limitation outcome measure scores were analysed from baseline to final assessment (time point 2 – time point 5).

We assessed kinematic performance across each deployment and from baseline to final assessment using the non-parametric Friedman's ANOVA to determine whether there were differences between measures at each time point; if this was indicated we used the Wilcoxon Signed Ranks Test with alpha set at 5%.

Statistical analysis was carried out using PASW Statistics 18 (Release 18.0.3).

Results

Use of the system in dual and single user mode

Figures 3a and 3b show respectively the number of days and minutes used by each child in each mode (single user and dual-user). The 11 children played the games system for a total of 253 days: 132 in single use mode (median days used per child was 13 days) and 121 in dual use mode (median days used per child was 12 days). Note that child 9 and child 10 did not play the game at all in dual-user mode. The median daily use was 9.27 minutes in single use mode and 11.2 minutes in dual use mode. Though this difference may appear to show a preference for dual-user exercise it was not statistically significant ($p = 0.214$, based on children's median daily use). However, the questionnaires returned by the participants showed a clear preference for dual-user games.

Qualitative surveys completed by school staff involved in the study indicated that they appreciated the importance of the games system in the potential rehabilitation and activity improvement of the children. In dual use, the children reported enjoying the collaborating games the most, although school staff reported that children with cerebral palsy appeared to enjoy the competitive nature of the other games.

Figure 3. Number of days used in school by each child (figure 3a) and number of minutes used by each child (figure 3b).

Functional measurement

Table 2 shows arm activity results from base line (time point 2) to the final assessment (time point 5) for the ABILHAND-kids and for the COPM Performance score for all 11 children. In each scale, improvement in arm activity is indicated by a positive change while deterioration in activity is shown by a negative change. On the primary outcome measure (the ABILHAND-kids), five children showed activity improvement, two showed deterioration in arm activity and four showed no change. On the COPM, two children showed arm activity improvement and nine showed no change. Differences between the baseline measures and final measures were not significant (ABILHAND-kids, p = 0.424; COPM, p = 0.484).

Table 2 Findings. Table shows total number of days and minutes that CAAR was used by each participant, and change in arm activity for each participant.

Kinematic measurement

Data analysis of kinematic scores showed no differences between time point 1 and time point 2, indicating that there was no change in arm kinematics in the 2 – 4 weeks before the games were deployed to schools.

Table 3 illustrates the kinematic assessments that showed statistically significant changes. All changes were improvements in arm kinematics. Because of recent lower limb surgery, child 11 was wearing full-leg plaster casts at the start of his part in the study. The plaster casts did not restrict his ability to play the games at school but did restrict operation of the CPKAT joystick from his seating at home. This prevented data collection at the beginning of the study (baseline and time point 1), so we omitted child 11 from further CPKAT assessments. Therefore, kinematic data analysis is available only for ten children.

No improvement was found from baseline to final assessment in any of the kinematic parameters except for TPA (defined in table 1) in the Tracing task. There were kinematic improvements for Path Length Time (hand speed) and Smoothness on the Pentagram task during the first deployment; Path Length, smoothness and Path Accuracy on the Figure of 8 task during the second deployment; and on the Tracing task, Path Length for the second deployment and TPA for the first deployment.

Discussion

The objective results of this study indicate that there is no preference for the children between playing the games in either dual-user mode (playing with friends) or in single-user mode (playing by themselves). However, these results were influenced strongly by the school environment e.g. school timetable and academic calendar, and although there was no significant difference between the times that children played in either mode, qualitative reports from the children indicated that they strongly favoured the collaborative mode (playing with their friends in non-competitive games [17]). The reason that playing times between single and dual-user did not differ was due to school timetabling: within each school, each mode was restricted to equal and similar amounts of available playing time. Between schools, playing times of the games varied considerably: two children (child 3 and child 4, both in the same school) exercised on over 30 days of the 40 days the system was available to them in the trial period, two other children (child 9 and child 10, both in the same school) played for less than 15 days. Large variation in the total number of minutes used for exercise is also apparent in figure 3b. Further analysis of the data shows that while in some schools the average usage was over 19 minutes per day in others it was as little as five minutes. This is less than our initial target of 30 minutes and indicates how difficult it is to take significant amounts of time out of the school day in a busy school's curricula. This is particularly noticeable at certain points in the calendar. For example, child 9 and child 10 did not play the games at all during the second deployment following their transition to a higher school year, because of the intensity of the opening weeks of the school year, and child 11's opportunity to play during the dual-user deployment was substantially reduced because National Curriculum assessments were underway in his year group. Rehearsals for the Nativity play also impacted on the December deployments.

Non-disabled children were able to play on the games system without interference in their academic programme and increasing the social contact of the child with cerebral palsy in their peer group. We experienced no difficulty in gaining support of school friends (or their parents) to play the games system except in one case, in which the child's parents incorrectly believed participating children would be withdrawn from curricular teaching periods.

The finding that arm activity did not significantly improve may be due to the poor responsiveness of the measures used. More likely, the limited time that the children played the games is unlikely to have made any functional impact. This is not to say that the contribution made by the games would not be beneficial when used in combination with a home-based system, with a concentrated burst of therapist-facilitated rehabilitation or following surgery or medical intervention e.g. botulinum treatment for spasticity. The kinematic assessments showed significant kinematic improvements in some movement parameters and in different tasks. Improvements were seen in the Pentagram for speed and smoothness of hand movements, Tracking for path length, smoothness and accuracy and Tracing for path length and TPA. There was no improvement in the Pentagram's Path Length, Figure of 8's Path Length Time and Tracing's speed and smoothness. However, the Tracing task is not about speed and children were encouraged to take their time and concentrate on accuracy; this is captured by TPA, which showed a significant improvement. The act of taking their time on this task also caused the movements to be cautious and broken, so smoothness was perhaps a poor parameter to measure for this task. The Pentagram showed no change in Path Length which may indicate that the children were accurate at following the set pattern, but gained arm speed and smoothness. The Tracking task showed no difference in Path Length Time, which is unsurprising since the speed of the object to be tracked is pre-determined, fixed and constant. Tracking also indicated improvements in accuracy (also indicated by improved path length) and smoothness, and Path Length and TPA (signifying improvements in accuracy and time taken) improved for the Tracing task.

The number of CKAT tests at each assessment proved difficult. Some children clearly tired of the assessments towards the end and strayed from the task in hand, for example demonstrating to the assessor on one occasion how fast they could make the cursor go in circles, thus rendering that task's measurements very inaccurate. In future, engagement with these CKAT assessment tasks might be increased by incorporating them within a game. Nevertheless, the observed kinematic improvements after less than

15 minutes activity per day suggest the potential for activity improvements if more time is spent playing the games system, perhaps in combination with a home-based system so that the amount of therapeutic activity achieved in other trials that produced benefits in functional activity is achieved e.g. 75 minutes per week [10]. Child 3 is uncharacteristic in this sample, having exercised on 29 out of 40 possible days yet showing a trend of deteriorating functional scores in all three scales, however it should be noted that on those 29 days child 3 only exercised for 8.4 minutes on average, the third lowest daily average recorded in the trial.

In conclusion, Computer-Assisted Arm Rehabilitation systems can be successfully installed in schools, but their daily use depends on the academic year and the pressures of the current school schedule e.g. transition pressures early in the new school year or National Curriculum assessments. Children prefer to play against or with their friends rather than on their own, increasing the value of school-based deployments, however the time available for using the system (and receiving adequate rehabilitation) is limited. Arm activity showed no significant changes in the limited time that children played the games system, but there were significant improvements in arm kinematics. Following the success of the feasibility studies of the equipment in home and schools, an investigation into use of home-based Computer-Assisted rehabilitation following botulinum treatment for arm spasticity in this population is underway. We also propose that further investigations might include the use of similar technology installed in schools to supplement a structured rehabilitation programme that includes therapistsupported exercises, home-based Computer-Assisted Arm Rehabilitation or following surgery.

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Conflict of interests

The authors declare no conflict of interests.

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Figure 1. The Computer Assisted Arm Rehabilitation (CAAR) games system. Two adjustable height powered robotic joysticks and associated hardware are housed in a portable trolley system. The bi-manual switch and emergency stop are illustrated.

Powered robotic joystick

Figure 2. The CKAT system. Left: illustrates the large range of motion passive joystick and laptop computer which implements the software programme tasks. Right: The CKAT tasks which the child performs using the system on the left a) practice tracing, b) pentagram, c) figure of 8, d) untimed tracing.

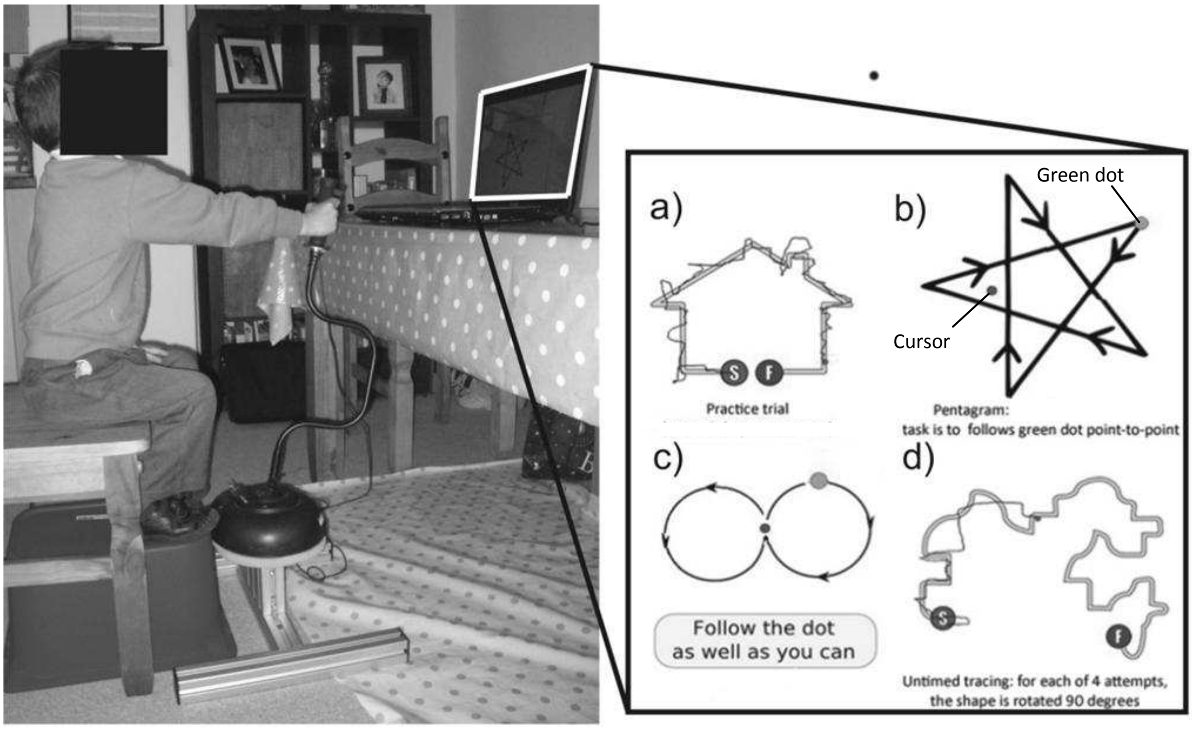

Figure 2. Number of days used in school by each child (figure 3a) and number of minutes used by each child (figure 3b).

Figure 3a Number of Days Used

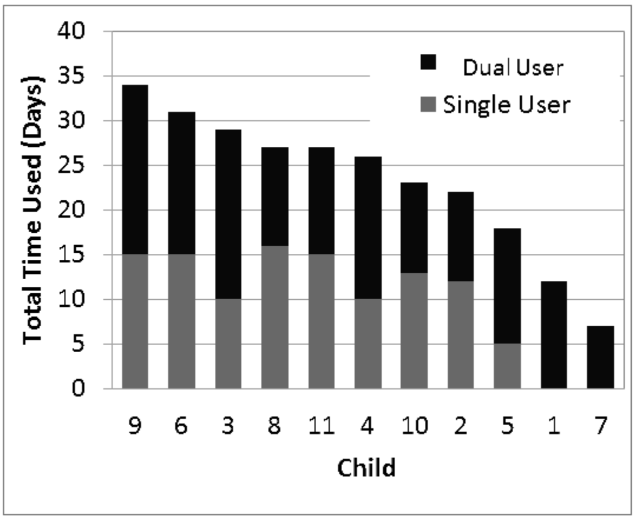

Figure 3b Number of Minutes Used

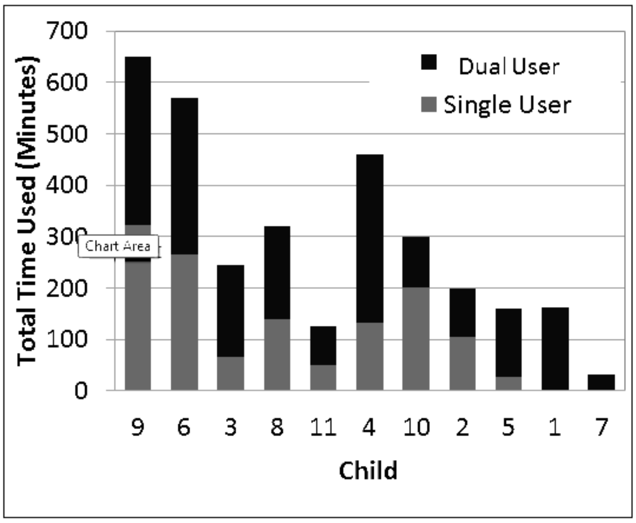

Table 1. Kinematic Parameters, as defined and measured by the developers of the CKAT, Culmer et al [25]

TASK & OUTCOME PARAMETER	DESCRIPTION	REASONING
PENTAGRAM		
Path Length	The distance travelled during each point-to-point movement.	Indicator of overall performance
Path Length Time	The time taken to travel the path length.	Indicator of hand speed
Normalised Jerk index (NJ) (smoothness)	Measure of the smoothness and time taken for a discrete movement. A maximally smooth point-to-point movement of the Pentagram would achieve a smoothness index of 7.75	Smooth movements are more energy efficient
FIGURE OF 8		
Path Length	The distance travelled during each point-to-point movement.	Indicator of overall performance
Path Length Time	The time taken to travel the path length.	Indicator of overall performance
Normalised Jerk index (NJ) (smoothness)	Measure of the smoothness and time taken for a discrete movement. A maximally smooth point-to-point movement of the Pentagram would achieve a smoothness index of 7.75	Smooth movements are more energy efficient
Path accuracy (RMS mean)	The position of the onscreen cursor controlled by the child via the joystick is monitored with reference to the position of the target moving along the Figure of 8 trajectories. RMS mean is a value of mean error.	Indicator of overall performance
TRACING		
Path Length	The distance travelled during each point-to-point movement.	Indicator of overall performance
Path Length Time	The time taken to travel the path length.	Indicator of overall performance
Normalised Jerk index (NJ) (smoothness)	Measure of the smoothness and time taken for a discrete movement. A maximally smooth point-to-point movement of the Pentagram would achieve a smoothness index of 7.75	Smooth movements are more energy efficient
Path Accuracy	The movement trajectory compared against a reference trajectory.	Indicator of overall performance
TPA (Time/Path Accuracy)	A product of Path Accuracy and Path Length Time; TPA allows comparison of children who sacrificed speed for accuracy and vice versa.	Indicator of overall performance

Table 2 Findings. Table shows total number of days and minutes that CAAR was used by each participant, and change in arm activity for each participant.

	Number of days played (days)		**Max time played in a day (mins)**	**Total time used per child (mins)**		**Total use (mins) (combined single and dual)**	**Median daily use (mins)**	**Median per day (mins)**	**Change in ABILHAND-kids score (logits)**	**Change in COPM score (out of 10)**
Participant	Single use	Dual use		Single use	Dual use	Single and dual use Combined (mins)	Single use	Dual use	Change of more than 0.45 indicates functional difference	Change of 2.0 or more indicates functional difference
1	10	18	11.24	47.27	123.26	170.53	4.55	6.37	-0.169	1
2	4	12	8.79	17.28	104.50	121.79	3.57	8.98	0.657	1.6
3	15	16	24.43	239.38	262.77	502.15	14.55	15.65	-0.645	-1.8
4	15	19	39.69	298.83	297.95	596.78	18.79	14.07	-0.409	-0.2
5	13	9	10.18	98.20	80.12	178.31	8.38	10.18	0.632	0.8
6	16	12	21.41	175.74	133.27	309.01	11.71	10.85	0.875	2.2
7	14	9	26.94	182.24	65.52	247.76	12.52	7.12	-0.844	-0.8
8	10	15	29.31	112.96	286.36	399.32	11.34	20.36	0.534	1.8
9	7		6.54	21.45		21.45	3.23		1.473	3.2
10	12		23.60	149.88		149.88	11.06		0.305	0.66
11	16	11	20.36	110.61	157.22	267.83	5.67	15.24	-0.439	0.8

Median	13 days	12 days	TOTAL:	1453.83	1510.97				0.305	0.8
TOTAL DAYS	132 days	121 days								

CAAR : Computer-Assisted Arm Rehabilitation games system

ABILHAND-KIDS : clinically significant change indicated by a change in score greater than the standard error (0.45)

COPM: Canadian Occupational Performance Measure (clinically significant change indicated by score change of 2.0)

Table 3. Kinematic outcomes. All differences were improvements in kinematics.

TASK Outcome Parameter	**Result**
PENTAGRAM (aiming movements)	
Path Length (mm)	No difference between groups, p = 0. 445 (Friedman's ANOVA).
Path Length Time (seconds)	*Difference detected time point 2 to time point 3, p = 0.028 No difference baseline to final assessment (p = 0.508)
Normalised Jerk index (NJ) (smoothness) **no units**	*Difference detected time point 2 to time point 3, p = 0.005 No difference baseline to final assessment (p = 0.241)
FIGURE OF 8 (tracking task)	
Path Length (mm)	*Difference detected time point 4 to time point 5, p = 0.022 No difference baseline to final assessment (p = 0.241)
Path Length Time (seconds)	No difference between groups, p= 0.222 (Friedman's ANOVA)
Normalised Jerk index (NJ) (smoothness) **no units**	*Difference detected time point 4 to time point 5, p = 0.047 No difference baseline to final assessment (p = 0.799)
Path accuracy (RMS mean) **no units**	*Difference detected time point 4 to time point 5, p = 0.037 No difference baseline to final assessment (p = 0.203)
TRACING	
Path Length (mm)	*Difference detected, time point 4 to time point 5, p = 0.028 No difference baseline to final assessment (p = 0.203)
Path Length Time (seconds)	No difference between groups,, p = 0.398 (Friedman's ANOVA)
Normalised Jerk index (NJ) (smoothness) **no units**	No difference detected, p = 0.398 (Friedman's ANOVA)
TPA **no units**	*Difference detected time point 2 to time point 3, p= 0.022 *Difference detected Baseline to Final Assessment (p = 0.007)