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Preston, N, Weightman, A, Culmer, P et al. (2014) The Cerebral Palsy Kinematic Assessment Tool (CPKAT): feasibility testing of a new portable tool for the objective evaluation of upper limb kinematics in children with cerebral palsy in the non-laboratory setting. Disability and Rehabilitation: Assistive Technology. 1 - 6. ISSN: 1748-3107

https://doi.org/10.3109/17483107.2014.951974

CPKAT: feasibility testing of a new tool for the objective evaluation of upper limb kinematics in children with cerebral palsy in non-laboratory settings

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Recognisable persons: Recognisable person is child of lead author, publication of photograph is authorised.

Running title: Cerebral Palsy Kinematic Assessment Tool

Key words: portable, upper-limb, kinematic assessment, children, cerebral palsy

Implications for rehabilitation:

- This paper demonstrates the feasibility of evaluating upper limb kinematics in the home using CPKAT, a portable laptop-based evaluation tool
- We found that CPKAT is easy to set up and use in home environments and yields useful kinematic measures of upper limb function
- CPKAT can complement less responsive patient-reported or subjectively evaluated functional measures for a more complete evaluation of children with cerebral palsy. Thus, CPKAT can help guide a multi-disciplinary team to more effective intervention and rehabilitation for children with cerebral palsy

Abstract

CPKAT: feasibility testing of a new tool for the objective evaluation of upper limb kinematics in children with cerebral palsy in non-laboratory settings

Purpose

Efficacy of treatment to improve upper-limb activity of children with cerebral palsy (CP) is typically evaluated outside clinical/laboratory environments through functional outcome measures (e.g. ABILHAND-kids). This study evaluates CPKAT, a new portable laptop-based tool designed to objectively measure upper-limb kinematics in children with CP.

Method

Seven children with unilateral CP (2 females; mean age 10y 2mo (SD 2y 3mo), median age 9y 6mo, range 6y 5m, MACS II – IV) were evaluated on copying, tracking and tracing tasks at their homes using CPKAT. CPKAT recorded parameters relating to spatiotemporal hand movement: path length, movement time, smoothness, path accuracy and root mean square error. The Wilcoxon Signed Ranks Test explored whether CPKAT could detect differences between the affected and less-affected limb.

Results

CPKAT detected intra-limb differences for movement time and smoothness (aiming), and path length (tracing). No intra-limb tracking differences were found, as hypothesised. These findings are consistent with other studies showing that movements of the impaired upper limb in unilateral CP are slower and less smooth.

Conclusion

CPKAT provides a potential solution for home-based assessment of upper limb kinematics in children with CP to supplement other measures and assess functional intervention outcomes. Further validation is required.

INTRODUCTION

Cerebral palsy (CP) is a relatively prevalent neurological disorder in children, occurring in 1.5 - 2.0 per 1000 live births[1]. Impairment of upper limb movements, characterized by increased trajectory duration, reduced speed (peak and average), increased variability and less straight hand trajectories[2-4], is present in up to 80% of children with CP[5]. Upper limb difficulties can cause activity limitation for children with CP (where activity is defined as the execution of a task by an individual[6]). Physiotherapy and occupational therapy focuses on maximizing activity and treatment efficacy is typically evaluated through patient-reported or functional (activity performance) outcome measures. Nonetheless, recent reviews[7-9] and advances in psychometric techniques (such as Rasch analysis[10]) have raised questions about the validity of existing tools, with issues raised regarding their responsiveness and reliability and the use of ordinal data in mathematical calculations and outcome scores[11-13]. There are compelling arguments that only interval-level outcome scores are acceptable in research and clinical practice[11,12] but many current measures provide ordinal scores with wide confidence intervals[11], which can give misleading information about the degree of improvement in performance[14]. Poor responsiveness is one drawback with many measures[15-17], potentially resulting in the discontinuation of an effective treatment approach. Even when responsiveness is not an issue, other problems are often present. For example, the Canadian Occupational Performance Measure (COPM) and the Goal Attainment Scale (GAS) are responsive[18] but have psychometric limitations[13] regarding the inappropriate use of mathematical techniques, the presence of wide confidence intervals and inaccuracies within the ordinal outcome data[11].

Spatiotemporal analysis of upper limb movement has been suggested as a complementary assessment measure for the guidance and evaluation of CP treatment because objective kinematic data provide fine-scale information that is not captured by existing patient-reported or functional outcome measures. Thus, kinematic evaluation can improve planning for more appropriately-targeted treatments[2,19,20] (e.g. by analyzing compensatory movement strategies and considering the kinematics within the context of surgery or pharmaceutical anti-spasticity treatment[19]). There is no suggestion that the evaluation of movement is a substitute for the assessment of activity or that improvement in kinematic indices indicates gains in activity level. But upper limb kinematic parameters characterise the movements that ultimately underpin improvements in activity (the ultimate goal of rehabilitation).

The impact of therapy type, frequency and intensity is poorly researched with studies into upper limb rehabilitation showing a wide variety of prescribed approaches[21-23]. An objective measure of upper limb kinematics might detect the presence of reliable but subtle improvements that are not sufficiently large to be captured by functional measures. It follows that upper limb kinematics might indicate that a particular therapeutic approach has merit but needs a greater intensity to achieve functional gain. Moreover, kinematic data provide a rich insight into the characteristics of how movements unfold over time (through indices such as speed, smoothness and acceleration profiles) and thus provide insights into the control strategies adopted by individuals.

There are disadvantages with kinematic evaluation. It is often expensive, requires specialist staff and is usually undertaken in laboratory and hospital environments (as the equipment is typically large, cumbersome and sensitive to disturbance). This means that kinematic evaluation normally necessitates repeated (and often inconvenient) travel for the family. We encountered these barriers within our own research when we used kinematic recording systems to evaluate children's upper limb abilities[24]. Our experiences suggested the potential benefit of a system that could provide kinematic assessment through a portable, low cost and easy to use system. Recent technological advances have allowed such systems to be developed for children with less severe deficits in upper limb function[25]. Inspired by validated paper-based assessments for children with movement difficulties[26], Culmer et al.[25] used lap-top based aiming, tracking and tracing tasks to capture the core manual motor skills associated with handwriting.

We postulated that the Culmer et al.[25] tasks could be adapted for children with CP and produce similar kinematic measures as previous laboratory based studies[2,3,20]. We therefore created the Cerebral Palsy Kinematic Assessment Tool (CPKAT) – an adaptation of Culmer et al.'s system[25] but designed for children with CP. CPKAT comprises the same portable laptop and software but uses an adapted gaming joystick (Sidewinder II model: Microsoft)[24] to allow the user to control a cursor on the computer screen. The joystick requires movements of the upper limb around the shoulder and elbow joint and provides an expanded workspace (available space for hand movement in the transverse plane of 35 cm by 35 cm). The joystick was further adapted to remove resistance to movement (see figure 1). The system has a small footprint making it ideal for use in the home where space can often be limited. The system is quick and easy to set up ensuring efficient use of therapist time when in the home. CPKAT tasks are designed to elicit useful descriptive spatiotemporal characteristics of movement (i.e. speed, smoothness and accuracy) in the sagittal and coronal plane.

This feasibility study was designed to: (i) test the capability of CPKAT to capture high quality kinematic data in a non-laboratory setting; (ii) compare the findings to previous kinematic evaluations in the CP population; (iii) investigate whether CPKAT could detect differences between the impaired and unimpaired arms of children with unilateral CP. We explored three manual control tasks that target different neural control mechanisms: aiming, tracing and tracking. These tasks are known to differentiate between affected and non-affected hands in the unimpaired population[25]. We hypothesised that CPKAT would provide data that could distinguish between the limbs on the aiming and tracing task. Conversely, we hypothesised no performance difference between the limbs on the tracking task (as reported within the unimpaired population) as this task is limited by central predictive mechanisms rather than peripheral limb control.

The ability to measure intra-limb differences would indicate that the system was capable of generating meaningful measures. It would also provide confidence that these measures have clinical relevance. For example, a therapist might select an intervention goal of decreasing the impairment of the paretic limb in unilateral CP. An improvement in the paretic limb would result in a decrease in the intra-limb differences and it would therefore be clinically useful to measure such decreases so that progress can be monitored. Moreover, this would open up the possibility of investigating the relative efficacy of different therapeutic regimes and allow detailed explorations of the optimal frequency and intensity for intervention programmes.

METHOD

This trial was a sub-study of a larger study testing novel interactive assistive (robotic) rehabilitation technology for children with cerebral palsy (NIHR-funded research grant K005). We received approval from the West Leeds Research Ethics Committee (REC reference 09/H1307/48) to conduct this research. Inclusion criteria were children with cerebral palsy aged 5 – 12 years who had upper limb weakness or spasticity causing difficulty with voluntary arm movement. Appropriate children were identified and approached through local community occupational and physiotherapy teams. Table 1 presents the characteristics of the participating children (for the purposes of describing the level of impairment the Manual Ability Classification System level[27] refers to the child's manual ability using their impaired upper limb when handling objects in daily activities, rather than their overall manual ability).

Table 1. Demographic information of participants

Participant id	Gender	Age at assessment	Affected upper limb	Manual Ability Classification (MACS)	Gross Motor Function Classification (GMFCS)
1	Female	12 years	Right upper limb	IV	II
2	Male	8 years 8 months	Right upper limb	IV	II
3	Male	12 years 1 month	Right upper limb	II	II
4	Male	10 years 6 months	Left upper limb	II	II
5	Male	9 years 6 months	Right upper limb	III	II
6	Female	6 years 10 months	Right upper limb	III	II
7	Male	9 years 6 months	Right upper limb	III	II

Both parents and children gave written informed consent (or assent for the younger children) to participate and for results of the study to be published. The children had sufficient cognitive ability to be able to play simple computer games. Children were excluded from participation in the trial if they had undergone upper limb surgery within the previous four months.

Kinematic evaluation sessions with CPKAT took place at the child's home in the presence of a parent or grandparent. Children wore hand orthotics (e.g. hand splints) when using CPKAT if orthotics were usually worn for daily activities. The researcher, a paediatric physiotherapist, sat alongside the child to explain each task and to offer encouragement. CPKAT, consisting of the modified Microsoft gaming joystick and a laptop, took only a few minutes to set up (booting up of the laptop and starting up the CPKAT software). Each child was positioned as illustrated in figure 1, sat on a firm chair in an upright forward-facing position with feet on a supporting surface and the adapted joystick placed between the child and the laptop, as close to each as possible while allowing for a full range of movement of the joystick. The laptop was positioned with the screen top at eye level and angled for the child's optimal viewing, and to avoid glare or reflections from lights and windows. Distractions were minimised (e.g. television off, siblings exiled).

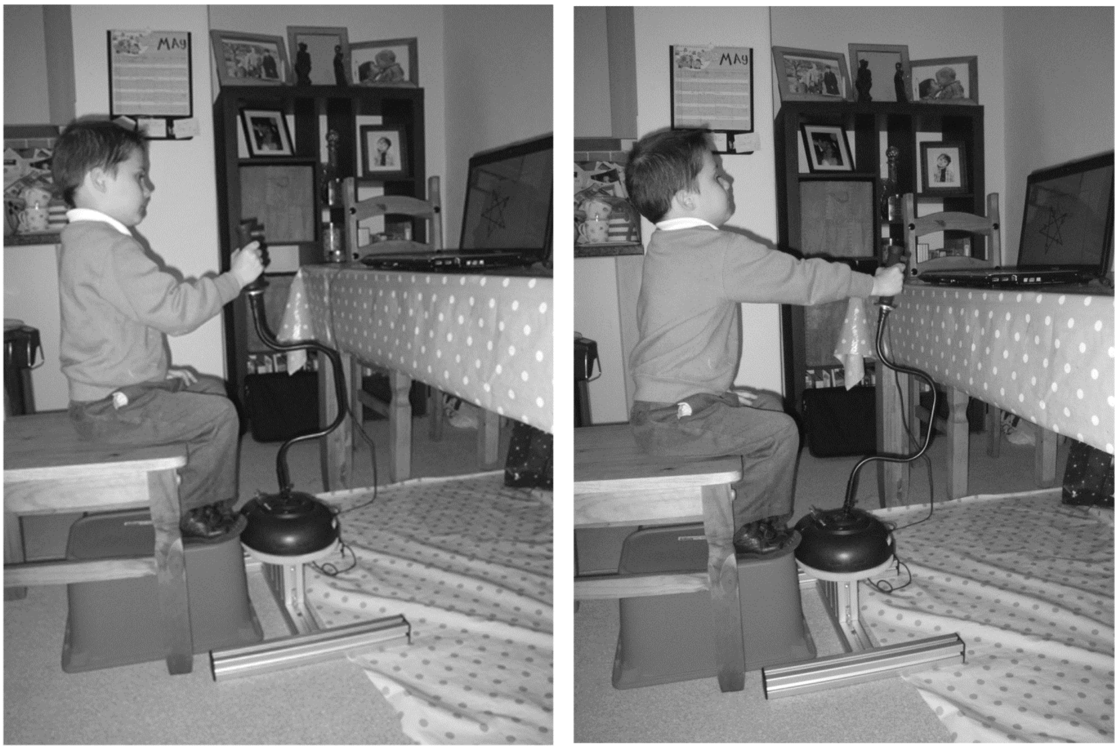


Figure 1. Five year old boy using CPKAT (model not a participant).

The CPKAT kinematic assessment consisted of four separate tasks: a practice task (carried out twice, to accustom the child to use of the joystick and control of the on screen cursor movements); an aiming task; a tracking task; and a tracing task.

Aiming task. The aiming task consists of two attempts at a series of aiming movements around a pentagram shape, guided by a target sprite that moved from one point of the pentagram to the next with each successful aiming motion. There were a maximum of 24 discrete movements (point to point) and the task lasted up to 60 seconds. Data were recorded for each discrete point-to-point movement even if the child did not achieve all 24 movements within 60 seconds. Children were asked to complete the task as quickly as possible. The kinematic parameters measured by CPKAT in the aiming task were movement time and smoothness (normalised jerk). Movement time (MT) was calculated for each of the discrete aiming movements and defined as the time between departure from one target location and arrival at the next one (i.e. a composite measure of the time taken to prepare and then execute each aimed movement), in seconds (fast MTs were indicative of an optimal task response). Smoothness was calculated using the ‘normalised jerk’ index[25]. Jerk is the time derivative of acceleration and is minimised in smooth movements. Normalised jerk is normalised with respect to time and distance so that trajectories of different durations and lengths can be compared, and the measure is consequently unit less. A maximally smooth 1D trajectory that starts and ends at rest is described by a quarter cycle of a sine wave, which gives a normalised jerk of 7.75.

Tracking task. Four timed trials to follow a green circle moving in a figure of 8 pattern were completed by the children. The first two trials were at a slow speed and the second two at a faster speed; each task lasted 31 seconds. The speed of the target circle to be tracked was pre-determined and fixed. The kinematic parameters measured by CPKAT for the tracking task were the smoothness of the movements and the accuracy of the position of the cursor in relation to the tracked target circle (RMSE). Root Mean Square Error (RMSE) is a measure of the spatio-temporal accuracy of participant’s’ tracking, provided an index of performance on the tracking task. RMSE was calculated as the straight-line distance in millimetres between the centre of the moving target and the end-point cursor for each sampled point during the time-series. For each tracking trial a value for RMSE was calculated and statistically analysed.

Tracing task. Four untimed tracing tasks (identical shape rotated 90°) were completed by the children. There was no time limit for this task as the emphasis was on accuracy. Children were instructed to take as much time as they needed to trace the shapes as accurately as possible. The kinematic parameters measured by CPKAT for the tracing task were path length (the total distance of the path followed by the joystick) and path accuracy. Path accuracy for each trial was defined as the arithmetic mean (in mm) across all samples within each trial for the distance from the cursor to the idealised reference path. The tasks were conducted in the order given so that no advantage or observation could be attributed to differing order of tasks. Children completed all tasks first using the most impaired arm and then completed the tasks again using the least impaired (affected) arm. This order was dictated by the constraints of the larger trial in which the children were participating. The complete session took between 10 and 15 minutes.

Children 1 and 2, both MACS Level IV, were unable to achieve a hand grip on the joystick handle due to increased tone in the hand and arm, and did not complete any timed tasks fully. These children were permitted to adapt their hold on the joystick to complete the tasks e.g. to rest their hand on top of the joystick with pronated forearm and hand (as if gripping a computer mouse). All of the children were able to use the system productively, and kinematic data were collected for all of the children. The parameters recorded were easily retrieved from the laptop using Excel spreadsheets. All children reported that they enjoyed using CPKAT and the researcher reported no problems with transportation of the CPKAT equipment, its set up and its use.

To determine whether CPKAT could differentiate between the affected and non-affected upper limb, we used the non-parametric Wilcoxon Signed Ranks Test with alpha set at 5%. Statistical analysis was carried out using PASW Statistics 18 (Release 18.0.3). We took the median of the recorded values and used the best performance recorded by the child. We used median values as these provide a robust measure of central tendency that is less affected by outlying values.

RESULTS

In the aiming task, CPKAT differentiated between the affected and non-affected side for both movement time (non-affected side was 21.9% quicker, $p = 0.028$) and smoothness (non-affected side showed positive difference of 58%, $p = 0.018$).

We hypothesised no intra-limb differences in the tracking task and in line with this prediction there were no differences found between the affected and the non-affected side for any of the spatiotemporal parameters, either in the fast or slow tracking task.

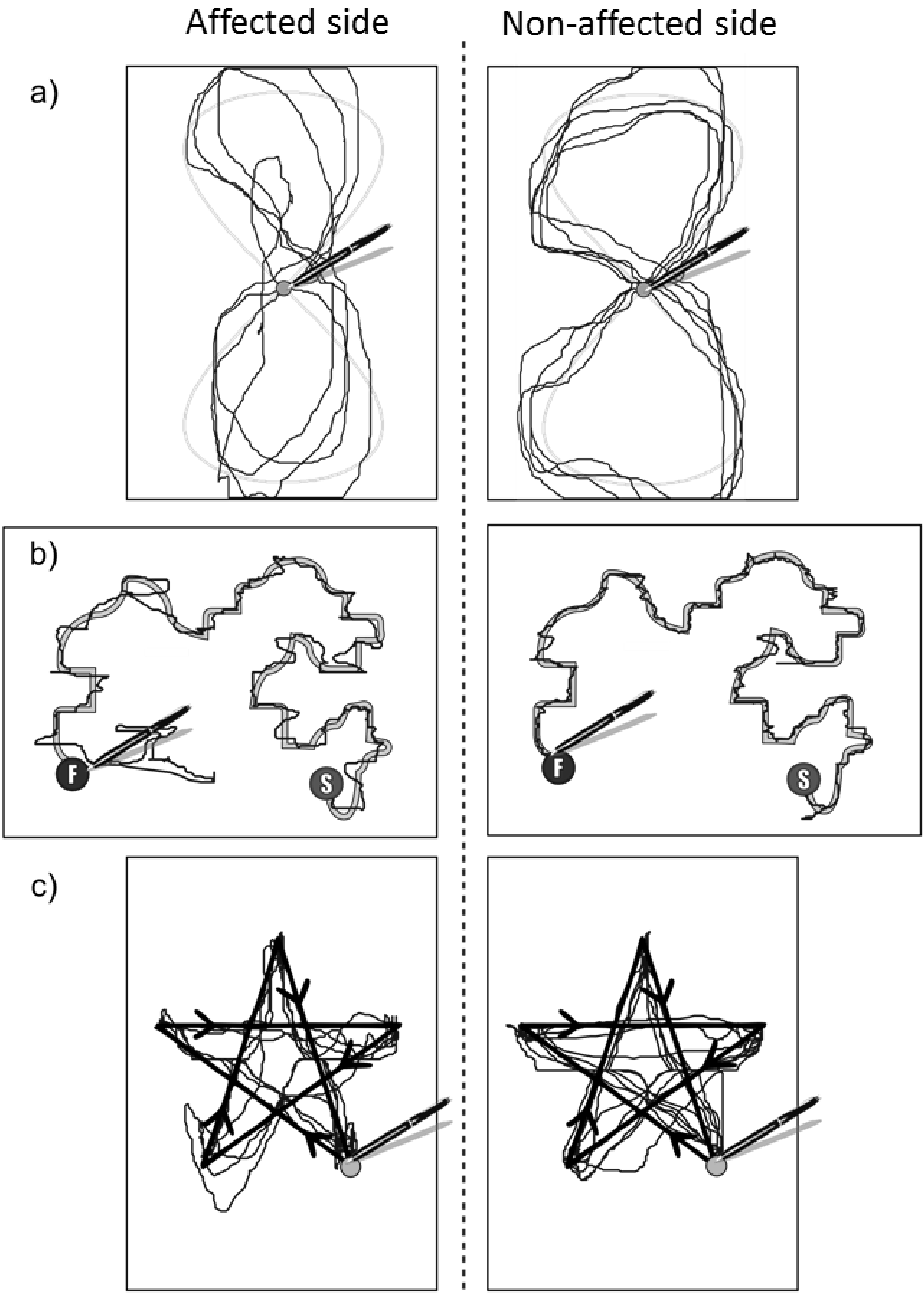
In the tracing task, CPKAT differentiated between the affected and non-affected side for Path Length (non-affected side was 21.5% shorter $p = 0.028$). Path Accuracy was close to statistical significance but did not cross the 5% threshold ($p = 0.063$) or TPA. Full results are given in table 2.

Table 2. Summary of CPKAT kinematic parameters.

TASK and PARAMETER		Median	IQR	Difference between affected and unaffected arms
AIMING TASK				
Movement time	**Affected**	2.55	2.43 – 4.06	non-affected side 21.9% quicker, p = 0.028
	Unaffected	1.99	1.84 - 2.16	
Smoothness	**Affected**	1255.63	1013.51 - 2738.28	non-affected side 49.32% smoother, p = 0.028
	Unaffected	636.31	534.84 - 1069.94	
TRACKING TASK (FAST)				
Smoothness	**Affected**	108786	78941 - 167272	No significant difference, p = 0.499
	Unaffected	102709	65190 - 129132	
RMSE	**Affected**	29.33	25.46 – 43.37	No significant difference, p = 0.176
	Unaffected	32.64	17.22 – 34.45	
TRACING TASK				
Path length	**Affected**	901.34	685.36 – 947.77	non-affected side 21.5% shorter, p = 0.028
	Unaffected	707.31	674.91 – 830.14	
Path accuracy	**Affected**	2.32	1.83 – 2.74	No significant difference, p = 0.063
	Unaffected	2.34	1.31 – 2.66	

Figure 2 shows the recorded movements of child 1 after performing the CPKAT tasks with each upper limb, and illustrates the difference between limb kinematics for that child. In figure 2a, child 1 recorded 158116.8 (non-affected arm) and 110514.0 (affected arm) data for smoothness (no units). For the tracing task in figure 2b, the child’s Path Length was 975.5 mm and 1163.8 mm (non-affected and affected arm respectively), and the path accuracy was 1.50 mm and 5.33 mm (non-affected and affected arm respectively). For the aiming task (figure 2c), child 1 performed point-to-point movements in 1.10 seconds and 1.23 seconds (mean values, non-affected and affected arm respectively); smoothness was recorded at 581.6 and 1275.4 (mean values, non-affected and affected arm respectively).

Figure 2. Illustration of movements completed by child 1 during CPKAT tasks, affected versus non-affected upper limb: a) figure of 8 (fast); b) tracing task; c) aiming task.



DISCUSSION

CPKAT was successfully used in a non-laboratory setting to record kinematic parameters from the upper limb of all children who participated in the study. No problems were reported by the researcher in the transportation, set up and use of the CPKAT system. All children reported enjoying the tasks. The critical question then becomes whether CPKAT can capture kinematic data with the potential to allow detection of changes in kinematics in children with CP? We addressed this question by comparing the kinematics for the affected and unaffected limbs of the children. CPKAT measured statistically significant differences between the affected and non-affected side of children in both the aiming and the tracing task. In the aiming task, there were no intra-limb differences in path lengths suggesting that the path followed by each child was similar for each arm but the movement was faster and smoother for the non-affected arm. In the tracing task, there was a significant difference between the arms for path length, with the non-affected arm tracing a path over a fifth shorter than the affected arm. Our findings are consistent with previous reports within the literature of reduced performance in the affected arm of children with unilateral cerebral palsy[2,3].

We hypothesised that the limb differences would not be observed for the tracking task as the limiting factor for such tasks is the central ability to predict the moving target's trajectory with less demands made of the end effector (in contrast to the aiming and tracing tasks). Inspection of the data showed that the CPKAT measures for tracking were similar between the two limbs. In short, the CPKAT system was capable of generating useful kinematic data from children with CP in a non-laboratory setting.

These findings suggest that CPKAT can be plausibly employed in clinical trials where detailed kinematic data need to be collected in non-laboratory settings. There were no difficulties in understanding and executing the computer-oriented tasks themselves, however a number of issues arose when conducting the tests. Two children were unable to achieve a hand grip on the joystick due to increased tone in the hand and arm, and did not complete any timed tasks fully. Successful capturing of their kinematic data was still achieved through an adapted grip on the joystick. In future, difficulties with maintaining grip could be minimised by modification of the interfacing joystick to account for increases in tone and reduced supination, or contractures causing fixed pronation. Modifications under consideration include various sizes of spherical, circular or horizontally-positioned hand grips that can be attached to the joystick handle.

One major advantage of the laboratory-based evaluation of upper limb kinematics is the capability to also monitor and evaluate trunk and shoulder movements. Evaluating upper limb movements using CPKAT does not account for shoulder and trunk movements. There are a number of ways of addressing this. Firstly, the CPKAT software and hardware includes a miniature inertial measurement unit (XSENS motion tracking technologies, Culver City, California), which measures 3-dimensional acceleration of the surface to which it is attached e.g. the shoulder. We are also developing a wireless system that allows real-time monitoring and recording of the distance between the shoulder and the laptop during the tasks. This system can freeze the screen task if the user moves within a pre-defined distance, encouraging the user to refrain from using excessive trunk movement to compensate for restricted arm movement.

In conclusion, this study demonstrates that CPKAT has the potential to evaluate upper limb kinematics in children with cerebral palsy outside the laboratory setting. CPKAT is not designed to replace large lab-based kinematic measurement systems but rather complement them and provide a portable tool for monitoring and evaluating changes in upper limb kinematics in non-laboratory settings. Future plans include studies to test the psychometric reliability of CKAT, and to investigate whether CPKAT can detect kinematic changes to the affected upper limb following use of assistive gaming technology following botulinum treatment of the affected arm.

Conflict of interests: The authors report no conflicts of interest.

Acknowledgements

This article presents independent research funded by the National Institute for Health Research (NIHR) under a Clinical Doctoral Research Fellowship. The views expressed in this publication are those of the authors and not necessarily those of the NHS, the NIHR or the Department of Health.

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