Three-dimensional analysis of performance of an upper limb functional task among adults with dyskinetic cerebral palsy

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1. Introduction

Dyskinetic cerebral palsy (DCP) is one of the most debilitating forms of CP because it causes severe motor impairment [1]. In patients with this disease, primitive reflex patterns predominate, muscle tone varies and recurring, uncontrolled, involuntary, and occasionally stereotyped movements appear [2]. However, there are few studies investigating the functional impairment of the upper limbs associated with DCP. Approximately 50% of this population has impaired shoulder or hand function [3].

Patients with DCP experience abnormal muscle activity stemming from the simultaneous, sustained contraction of the agonist and antagonist muscles during movement [4], resulting in difficulties maintaining spatiotemporal trajectories and considerable variability in their movements [5]. The most common manifestations are dystonia, chorea, and athetosis [6]. These involuntary movements can cause discomfort, interfere with voluntary movements, and limit or even impede upper limb function. Impairments in reaching, grasping and handling make daily activities such as dressing, eating, and maintaining personal hygiene difficult [7].

The lack of studies aimed at analysing movements in patients with DCP poses an obstacle to understanding the motor defects in their upper limbs. Coluccini et al. [4] studied the movements of reaching, grasping, and releasing objects in three children with

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DCP, and only Butler et al. [8] have analyzed the spatiotemporal variables involved in raising a cup to the mouth in their study of 12 children, including seven with DCP.

Such analyses have demonstrated how functional activities, such as the movements involved in raising a glass to one's mouth are performed by other types of patients with impaired upper limb function [12]. However, the few studies on the impaired movement associated with DCP conducted to date have only analyzed upper limb movement in children [4,8], despite the fact that deficits in childhood persist into adulthood and are aggravated by age [9,10].

The involuntary movements and spasticity that may accompany DCP lead to substantial changes in movement and contribute to functional impairment [2]. Analysing movement biomechanics in patients with DCP is fundamental to gaining a better understanding of these movements and establishing therapeutic interventions to inhibit undesirable movements and improve functional performance [11]. Such analyses have demonstrated how functional activities, such as the movements involved in raising a glass to one's mouth are performed by patients with impaired upper limb function [12].

Raising a glass to one's mouth involves the majority of joints in the upper limb and is a challenging but reproducible task for DCP patients. This activity also reveals motor deficits and allows a quantitative assessment of the effect of therapy [13]. The aim of the present study was to analyze the performance of adults with DCP during the task of raising mugs to their mouths through three-dimensional angular and spatiotemporal kinematics.

2. Methods

This study received approval from the local human research ethics committee under No. 429632/2011.

2.1. Volunteers

Volunteers were recruited from a list of 1166 patients treated at the Cerebral Palsy Clinic in 2009–2011. Patients younger than 18 and those with forms of cerebral palsy other than DCP listed on medical charts were excluded. Fifty-nine remaining patients were preselected and contacted by telephone to verify the eligibility criteria and potential for participation in the study.

DCP adults ($N = 16$, 10 males and six females with a mean age 29.63 ± 4.42 years) were selected through consecutive sampling to form the DCP group (Table 1). The following were the inclusion criteria: adults older than 18 years of either sex, involuntary dyskinetic movements of the upper limbs, capability of understanding simple verbal commands, capability of voluntarily moving the upper limbs during the task, agreement to participate in the study, and signature of a statement granting informed consent. Partition in physical therapy was neither an inclusion or exclusion criterion. The following were the exclusion criteria: joint deformities of the upper limbs; associated rheumatic, orthopedic, or neurological conditions affecting movements; history of bone or tendon correction surgery, or tendon or muscle transfers in the preferred upper limb; history of receiving botulinum toxin in the last six months; visual or hearing impairment and skin lesions at the sites where the markers would be placed.

Age-matched young adults ($N = 11$, nine females and two males with a mean age of 24.09 ± 3.73 years) were selected through verbal invitation at the university to compose the control group. Exclusion criteria for the controls were a history of surgical procedures on the preferred upper limb; uncontrolled health conditions; rheumatic, orthopedic, or neurological disease; visual or hearing impairments; and skin lesions at the sites where the markers would be placed (Table 1).

Table 1
Characteristics of the DCP patients ($N = 16$) and controls ($N = 11$) with group means and 95% confidence interval.

	Age (years)	Gender	Preferred arm	Height (m)	Weight (kg)	BMI	MACS
DCP	29	Male	Left	1.58	50	20	II
DCP	31	Male	Left	1.75	50	16.33	II
DCP	24	Male	Left	1.74	62	20.52	II
DCP	27	Female	Left	1.73	58	19.39	II
DCP	23	Male	Right	1.85	70	20.46	IV
DCP	32	Male	Left	1.53	55	23.5	IV
DCP	29	Female	Left	1.54	42	17.72	II
DCP	25	Male	Right	1.56	65	26.74	IV
DCP	37	Male	Left	1.70	52	17.99	III
DCP	47	Female	Left	1.54	55	23.2	IV
DCP	27	Female	Right	1.40	50	22.51	II
DCP	26	Male	Left	1.75	80	26.14	III
DCP	29	Male	Right	1.65	63	23.16	II
DCP	37	Male	Right	1.68	65	23.04	II
DCP	30	Female	Left	1.50	57	23.55	II
DCP	21	Female	Left	1.65	51	18.55	III
Controls	23	Female	Right	1.70	68	23.78	–
Controls	23	Female	Right	1.53	48	20.51	–
Controls	23	Male	Right	1.65	63	23.16	–
Controls	23	Female	Right	1.74	65	21.52	–
Controls	22	Female	Right	1.59	56	22.22	–
Controls	31	Female	Right	1.71	60	20.54	–
Controls	29	Female	Right	1.73	100	33.44	–
Controls	19	Female	Right	1.53	53	22.64	–
Controls	20	Male	Right	1.80	62	17.28	–
Controls	24	Female	Right	1.67	56	20.14	–
Controls	28	Female	Right	1.70	63	21.79	–
DCP = 16	29.62 (26.21, 33.04)	(6 F/10 M)	(5 R/11 L)	1.63	57.81	21.41	II(9); III(3)
Controls = 11	24.09 (21.58, 26.6)[a]	(9 F/2 M)	(11 R/0 L)	(1.57, 1.69)	(52.82, 62.8)	(19.81, 23.03)	IV(4)
				1.67 (1.61, 1.72)[a]	63.09 (54.0, 72.18)[a]	22.46 (19.74, 25.17)[a]	

DCP, dyskinetic cerebral palsy; F, female; M, male; R, right; L, left; m, meters; kg, kilograms; BMI, body mass index; MACS, manual ability classification system.
[a] Values expressed as the mean (95% confidence interval).

2.2. Physical exam and kinematics

The participant data collected included personal identification, age, medications, physical therapy participation, and surgical history. The patients were asked about their daily activities to determine which arm (preferred upper limb) they used in executing tasks. In the anthropometric evaluation, the following variables were measured by an investigator using a meter and a paquimeter: height, weight, distance between the acromion and the great tubercle of the humerus, hand thickness and width of elbow and wrist. The distance between the acromion and the great tubercle was a line from the base of the acromion marker to the great tubercle shoulder joint center. Hand thickness was the measure of anterior/posterior thickness between the dorsum and palmar surfaces of the hand. The width of the elbow was measured along the flexion axis (roughly between the medial and lateral epicondyles of the humerus) and the width of the wrist was measured at the position where the wrist marker was attached (roughly between the ulnar styloid process and radial styloid) [14].

To acquire the kinematic data, 15 reflective spherical markers measuring 14 mm were attached to anatomic sites [14] (Supplementary material). The kinematic data were captured using 10 infrared cameras (Vicon® MX 40, Oxford Metrics Group, Oxford, UK), with a capture frequency of 120 Hz. The three-dimensional reconstruction and processing of these markers' positions were performed using the Vicon Nexus 1.5® program (Oxford Metrics Group, Oxford, UK).

2.3. The task

All of the volunteers remained seated in chairs with an adjustable height for standardized positioning of the ankles, knees, and hips at angles of approximately 90° [16]. Two Velcro® straps crossing the patient's thorax were used to ensure stability and avoid interference from trunk movements during the task.

For each volunteer, a cylindrical mug (10.70 cm in height and eight cm in diameter) filled to 50% of its volume (total weight, 0.350 kg) to simulate the presence of liquid was placed at 75% of the maximum passive elbow extension (acromion-index tip) in the midline of the patient. The table was marked for the placement of the mug (corresponding to 75% of maximal passive preferred upper limb extension [8,13]) to ensure standardization of the initial position of the joints in the arm with the shoulder in the neutral position, the elbow in flexion, the forearm in the neutral position, and the hand securing the handle of the mug. The non-preferred upper limb was positioned alongside the body. From the initial position, the volunteer was instructed to lift the mug to his or her mouth, drink, and return the mug to its initial position. This sequence of motions was performed six consecutive times [14,15] at a comfortable velocity without the volunteer releasing the mug in the interval between each sequence. A preliminary execution of the task was first performed for training and orientation prior to the data acquisition.

2.4. Kinematic analysis of movement strategies

Spatiotemporal and angular kinematic variables were used to evaluate task performance. Eleven spatiotemporal variables were divided into temporal, velocity, and smoothness parameters (Table 2).

The spatiotemporal variables described the time needed to execute the going (lifting the mug to the mouth), adjusting (drinking), and returning (returning the mug to its initial position) phases of the task, as well as the ratio between the going and returning times. The beginning and end of each phase was defined by the velocity of the marker positioned on the third finger. The beginning was defined as when the velocity increased to more than 50 mm/s and the end was defined as when the velocity decreased to less than 50 mm/s [14]. The peak velocity time was defined as the time between the beginning of the going phase and the time at which the maximal velocity was reached. The flattening of the velocity curve was described as the percentage of time needed to reach peak velocity. The velocity analysis involved calculating the mean and peak velocities.

Table 2
Description of spatiotemporal kinematic variables.

Abbreviation	Variable	Unit	Parameter
Going phase	Lifting the mug to the mouth	s	Time
Adjusting phase	Simulation of drinking	s	Time
Returning phase	Returning the mug to the table	s	Time
G/R ratio	Ratio between going and returning	(*)	Time
TVp	Time require to reach peak velocity	s	Time
Flattening	Flattening of velocity curve	%	Time
Vm	Mean velocity	m/s	Velocity
Vp	Peak velocity	m/s	Velocity
NMU	Number of movement units	(*)	Smoothness
MIC	Mean index of curvature	(*)	Smoothness
M Jerk	Mean jerk	(cm/s^3)	Smoothness

s, seconds; %, percentage; m/s, meter per second.

The smoothness of the movement was assessed in the going phase by three variables: the number of movement units, characterized by the number of velocity peaks over a threshold represented by the 10% of the peak velocity; index of curvature, calculated by the ratio of the length of the trajectory of the three-dimensional marker on the third finger during the going phase and the straight line connecting the starting point and ending point; and jerk, characterized by either the rate of change in acceleration or the third-order or class derivatives of the position [14,17].

The angular variables were represented by shoulder flexion–extension, abduction–adduction and internal–external rotation, elbow flexion–extension and forearm pronation–supination. The start position, minimum and maximum angular values and range of motion (ROM) were also analyzed.

2.5. Kinematic data processing

The data were saved in a C3D format, imported and processed using a Smart Analyzer® (BTS, Milan, Italy). The coordinates of the three-dimensional markers were filtered through a Hamming low-pass filter with a 10-Hz cutoff frequency [18]. The trajectory and velocity thresholds of the third finger markers were computed using numeric differentiation to determine the going, adjusting, and returning phases of the movements [19].

The movement cycles were time-normalised (0–100%), and each calculated joint angle was visualized as a function of time.

2.6. Statistical analysis

A statistical power analysis was performed based on a pilot study performed with the first 11 patients and 10 controls; these individuals were also included in the main study. The index of curvature was selected because it is a measure of the trajectory complexity and able to detect differences in the trajectory between the patients and controls in the pilot study. We adopted a standard difference of 1 and a minimal detectable difference of 1.5 in the index of curvature based on our pilot study.

The calculation of the expected difference in the means between groups was performed with the use of a Wilcoxon Rank Sum test. Considering an alpha error of 0.05 and 80% power, 11 volunteers were determined for each group [20].

The repeatability of all of the variables used in this study was assessed with the intraclass correlation coefficient (ICC). ICCs values less than 0.20 were considered to reflect poor repeatability; values between 0.21 and 0.40, fair repeatability; values between 0.41 and 0.60, moderate repeatability; and values between 0.81 and 1.00, good repeatability [21].

The Kolmogorov–Smirnov test was used to determine the distribution of the data. The Mann–Whitney test was employed to identify differences in the spatiotemporal and angular variables between the DCP group and controls. The level of significance was set to 5% ($p < 0.05$). The Statistical Package for Social Sciences, version 15 was used for the analysis (SPSS Inc., Chicago, IL, USA) [20,22,23].

3. Results

3.1. Spatiotemporal parameters

Table 3 displays the smoothness, time, and velocity variables for both groups during the course of lifting a mug to the mouth. The time required for the going, adjusting, and returning phases was statistically significantly longer for the DCP group than controls. No statistically significantly differences were found between the two groups regarding the ratio between the time required for the going and returning phases. The mean and peak velocities during the movement were statistically significantly lower for the DCP group compared with the controls, and the time needed to reach maximal velocity was statistically significantly longer for the DCP group than for the controls. No statistically significantly differences between groups were found for the flattening of the velocity curve (peak velocity in movement cycle). The index of curvature, number of movement units, and average jerk were statistically significantly higher in the DCP group than in the controls.

3.2. Angular parameters

Table 4 displays the mean of the start position, minimum and maximum angular values and the ROM for the movements of the shoulder, elbow and forearm during all three phases for both groups. At the start position, the DCP group exhibited statistically significantly decreased shoulder flexion and increased elbow flexion and forearm pronation compared with the controls. While performing the complete task, the DCP group had a significantly decreased minimum angle for shoulder flexion and an increased minimum angle for shoulder abduction, elbow flexion and forearm pronation compared with controls. The maximum angles of shoulder and elbow flexion were decreased, and the maximum angles for forearm pronation were increased in patients compared with controls. The ROM for shoulder flexion, elbow flexion, and forearm pronation was statistically significantly lower in DCP patients than in controls. No statistically significantly differences were found between the groups with regard to abduction or internal rotation of the shoulder.

Fig. 1 shows the angular movements within both groups during the movement cycle.

3.3. Movement repeatability

DCP group demonstrated less repeatable movement among the six cycles than controls for the spatiotemporal and angular variables analyzed. However, adults in both groups displayed good intra-trial repeatability (ICC $\geq$ 0.81) (Tables 3 and 4).

4. Discussion

Movement analysis in adults with DCP is a challenge for researchers and physicians because this type of cerebral palsy can be characterized by dystonia, chorea, or athetosis or even a combination of these movement disorders [6]. The aim of the present study was to assess a large number of variables in an attempt to understand and quantitatively characterize dyskinetic movements and evaluate the functional task performance of patients with DCP. Spatiotemporal parameters such as duration, velocity, and trajectory can offer important quantitative information on the quality of upper limb movements [8] and help determine the extent to which impairment stemming from cerebral palsy affects these movements.

The DCP group performed the task more slowly than the control group, with significant differences in mean velocity, peak velocity, and time required to reach peak velocity. Consequently, the going, adjusting, and returning phases of the task were significantly longer in the DCP group. In a study of 12 children with cerebral palsy, including seven with DCP, Butler et al. [8] found a nearly two-fold increase in the total time required to reach for a glass, lift it to the mouth, and return it to its original position for cerebral

Table 3
Spatiotemporal parameters (time, velocity and smoothness) in the DCP patients and controls expressed as the median (interquartile range) and *P* value of ICC.

Spatio-temporal parameters	DCP		Controls	
	Median (IQR)	ICC	Median (IQR)	ICC
Time				
Going phase (s)	1.31 (1.01–1.76)[a,β]	0.954	1.12 (0.90–1.25)	0.965
Adjusting phase (s)	1.02 (0.52–2.05)[a,β]	0.985	0.40 (0.60–0.28)	0.946
Returning phase (s)	1.68 (1.42–2.33)[a,β]	0.753	1.21 (1.00–1.31)	0.984
G/R ratio	0.91 (0.55–1.25)	0.915	0.96 (0.90–1.10)	0.954
Velocity				
Vm (m/s)	0.32 (0.25–0.48)[a,β]	0.977	0.50 (0.46–0.57)	0.972
Vp (m/s)	0.59 (0.41–0.87)[a,β]	0.969	0.96 (0.78–1.03)	0.962
TVp (s)	0.38 (0.36–0.43)[a,†]	0.694	0.43 (0.30–0.52)	0.900
Flattening (%)	0.37 (0.26–0.54)	0.945	0.37 (0.11–0.41)	0.925
Smoothness				
NMU	8.20 (3.75–13.65)[a,β]	0.967	1.60 (1.20–2.20)	0.987
MIC	1.06 (1.03–1.16)[a,§]	0.966	1.03 (1.02–1.05)	0.979
M Jerk (cm/s^3)	44.68 (42.46–52.10)[a,§]	0.973	45.97 (43.77–48.09)	0.863

DCP, dyskinetic cerebral palsy group; *G/R* ratio, relationship between going and returning; Vm, mean velocity; Vp, peak velocity; TVp, time required to reach peak velocity; NMU, number of movement units; MIC, mean index of curvature; M Jerk, mean jerk; s, seconds; m/s, meters per second; cm/s, centimeter per seconds; %, percentage; ICC, intraclass correlation coefficient; IQR, interquartile range.

[a] Median difference between DCP and controls.
[†] Median difference is significant at the 0.050 level.
[§] Media difference is significant at the 0.01 level.
[β] Median difference is significant at the 0.001 level.

Table 4
Values for the start position and the minimum, maximum and range of motion (ROM) of the shoulder, elbow and forearm angles (in degrees) in the DCP and controls expressed as the median (interquartile range) and *P* value of ICC.

	Start position				Minimum				Maximum (at going)				ROM (absolute)			
	DCP		Controls		DCP		Controls		DCP		Controls		DCP		Controls	
	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$	Median (IQR)	$ICC_{(2,1)}$
Shoulder																
Flexion	27.2 (19.1–34.5)[a,β]	0.953	47.3 (31.2–63.1)	0.987	22.5 (14.5–33.4)[a,β]	0.941	46.2 (36.1–54.0)	0.991	37.8 (36.1–47.9)[a,β]	0.965	74.4 (59.5–81.0)	0.996	15.0 (10.1–19.1)[a,β]	0.854	25.4 (19.4–34.8)	0.986
Abduction	−12.8 (−21.7–(−3.2))	0.932	−10.5 (−13.1–(−0.1))	0.982	−21.1 ((−31.2)–(−11.7))[a,†]	0.974	−7.9. ((−15.4)–3.2)	0.989	−12.4 ((−22.8)–(−1.7))	0.967	−15.8 ((−26.2)–(−3.6))	0.983	10.2 (1.4–20.2)	0.911	6.1 (2.3–9.2)	0.910
Internal rotation	22.1 (1.3–42.1)[a,†]	0.915	10.3 (3.2–19.5)	0.978	8.3 ((−10.2)–24.1)	0.958	12.1 (3.2–23.1)	0.984	35.1 (1.4–65.8)	0.922	30.3 (25.2–37.8)	0.973	28.0 (15.6–47.2)	0.852	20.2 (15.2–23.9)	0.985
Elbow																
Flexion	71.6 (53.2–97.9)[a,§]	0.982	54.1 (48.3–61.2)	0.984	66.02 (57.5–87.8)[a,§]	0.991	58.7 (55.2–61.3)	0.981	116.4 (129.1–120.8)[a,§]	0.886	139.2 (135.2–142.3)	0.885	35.4 (31.3–39.4)[a,§]	0.967	78.6 (67.1–95.5)	0.859
Forearm																
Pronation	36.5 ((−3.1)–63.1)[a,β]	0.941	4.4 ((−6.1)–12.9)	0.953	20.7 (3.4–41.7)[a,β]	0.977	1.3 (8.4–(−6.7))	0.954	52.9 (31.1–70.1)[a,§]	0.99	21.3 (31.5–16.2)	0.889	23.7 (14.5–32.1)[a,β]	0.759	23.7 (19.0–29.5)	0.761

DCP, dyskinetic cerebral palsy group.
[a] Difference between DCP and controls.
[†] Difference is significant at the 0.050 level.
[§] Difference is significant at the 0.01 level.
[β] Difference is significant at the 0.001 level.

palsy patients compared with controls. The fact that patients with dyskinesia have difficulties performing sequenced movements [5] may explain the reduction in velocity and increase in the time required to execute the phases of this task.

The increase in time required for each specific task phase may be directly related to motor control. The lifting of the mug (going phase) is the phase consisting of acceleration, concentric muscle activation, and establishment of motor strategy so that the trajectory of the mug to the mouth is efficient. The adjusting phase requires a longer period of isometric activation to enable the precise coordination of the act of drinking. The returning phase is the longest, likely due to the need for increased precision and eccentric muscle action, which decelerates the upper limb at the moment during which the mug must return to its original position on the table [12]. The uncontrolled, random movements characterizing dystonia generate inconsistent movement patterns. Thus, the aim of performing slower movements is to enhance motor performance, harmony, and precision in the task at hand [14,24].

The smoothness parameters (index of curvature, mean jerk, and number of movement units) were significantly higher in the DCP group than the controls, demonstrating a relative loss of movement harmony compared with the controls. The increase in the number of movement units indicates a greater number of changes in velocity stemming from successive attempts to correct the fragmented movement [14]. The increase in the index of curvature is also related to the reduction in velocity and is a consequence of the movement fragmentation in the going phase [14,18,25]. The change in acceleration indicates less fluency in the movements of the upper limbs, and the increase in the index of curvature is proportional to the increase in the movement duration [26]. The attempts of DCP patients to correct movement and make it smoother are reflected in the increase in the mean jerk in these patients compared with controls [5].

Regarding the angular movements of the shoulder, elbow and forearm, the DCP group began the task with decreased shoulder flexion and increased shoulder internal rotation, elbow flexion and forearm pronation compared with controls. The mean ROM values for shoulder and elbow flexion and forearm pronation were significantly lower in the DCP group than in the control group, whereas no differences between the two groups were found for shoulder abduction or internal rotation ROM. For the control group, the going phase included shoulder flexion, abduction and internal rotation, elbow flexion and forearm pronation. The highest values for each of these movements were reached during the adjusting phase, and the returning phase included shoulder extension, adduction and external rotation and forearm supination. In contrast, the DCP group maintained the mean ROM for shoulder flexion, internal rotation, and pronation of the forearm throughout almost the entire movement cycle, whereas the shoulder abduction/adduction and elbow flexion–extension movements followed a similar pattern to that observed in the control group. The maximum ROM values for the DCP patients occurred during the returning phase, except for elbow flexion, which occurred during the adjusting phase.

The mean ROM values and respective standard deviation values displayed in Fig. 1 demonstrate that shoulder abduction alone was inconsistent in both groups, and elbow flexion was the only relatively consistent movement in the DCP group. The inconsistency in movement patterns results from an inability to exclude undesired components and compensatory movements [2,8,27]. Coluccini et al. [4] found that upper limb movements in DCP are accompanied by head movements. In our study, neck flexion was observed and facilitated the movement of the mug to the mouth even with the reduced ROM observed in the DCP group. Despite an attempt to evaluate these moments, the presence of involuntary movements and difficulty in maintaining markers attached to the exact position precluded quantitative measurement of compensations.

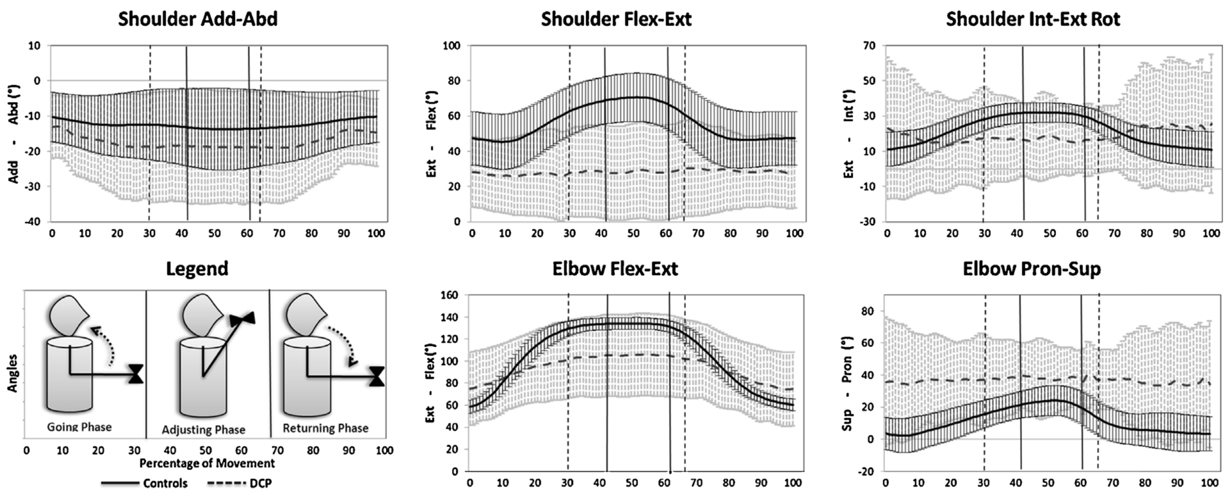

Fig. 1. Average angular movements of shoulder, elbow and forearm in DCP and controls during the cycle of movement in bringing the mug to the mouth and returning it to the table; percentages of movement phases, maximum, mean and standard deviation. Add–Abd is adduction and abduction, adduction is negative; Flex–Ext is flexion and extension, extension is negative; Int–Ext Rot is internal rotation and external rotation, external rotation is negative; Pron–Sup is pronation and supination, supination is negative. All values are in degrees.

Despite the fact that DCP patients exhibit increased variability in upper limb movements compared with healthy subjects [5], our study analyzed ICC by means of the spatiotemporal and angular variables, and the results indicated good intra-trial repeatability for both groups, *i.e.*, the DCP group exhibited change in movement performance compared with controls yet demonstrated consistency of motor strategy during the repeated execution of the same task. The ICC is a variance ratio for a sample of individuals and has some limitations in terms of interpretation, and therefore, the results need to be interpreted carefully. A more robust analysis of repeatability is necessary to better understand this phenomenon.

The present study was limited to assessing the kinematics of the upper limb. Simultaneous kinematic and electromyographic analyses may elucidate issues that are not yet fully understood. Despite being the correct procedure for isolating the movements of the upper limb, restriction of trunk movements does not reproduce a functional condition because the majority of upper limb movements performed by patients with DCP do involve the action and compensation of the trunk. Thus, although the biomechanical model employed offers good reproducibility [14,15], it may be considered too simple for assessing certain movements of the upper limbs. Nevertheless, the analysis performed in this study represents an important method for evaluating dyskinetic movements of the upper limbs in adults with DCP. Such an analysis is capable of quantifying both the level of motor impairment and the results of therapeutic interventions for DCP patients.

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Conflict of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version.

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