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Associated Reactions during a Visual Pursuit Position Tracking Task in Hemiplegic and Quadriplegic Cerebral Palsy

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Abstract

Most previous studies of associated reactions (ARs) in people with cerebral palsy have used observation scales, such as recording the degree of movement through observation. The sensitive quantitative method can detect ARs that are not amply visible. The aim of this study was to provide quantitative measures of ARs during a visual pursuit position tracking task. Twenty-three hemiplegia (H) (mean ± SD: 21y 8m ± 11y 10m), twelve quadriplegia (Q) (21y 5m ± 10y 3m) and twenty-two subjects with normal development (N) (21y 2m ± 10y 10m) participated in the study. An upper limb visual pursuit tracking task was used to study ARs. The participants were required to follow a moving target with a response cursor *via* elbow flexion and extension movements. The occurrence of ARs was quantified by the overall coherence between the movements of tracking and non-tracking limbs and the amount of movement due to ARs was quantified by the amplitude of movement the non-tracking limbs. The amplitude of movement of the non-tracking limb indicated that the amount of ARs was larger in the Q group than the H and N groups with no significant differences between the H and N groups. The amplitude of movement of the non-tracking limb was larger during non-dominant than dominant tracking in all three groups. Some movements in the non-tracking limb were correlated with the tracking limb (correlated ARs) and some movements that were not correlated with the tracking limb (uncorrelated ARs). The correlated ARs comprised less than 40% of the total ARs for all three groups. Correlated ARs were negatively associated with clinical evaluations, but not the uncorrelated ARs. The correlated and uncorrelated ARs appear to have different relationships with clinical evaluations, implying the effect of ARs on upper limb activities could be varied.

Key Words: associated reactions, cerebral palsy, hemiplegia, quadriplegia, upper limb

Introduction

Associated reactions (ARs) are involuntary movements occurring in one limb when the opposite limb is active (1, 5, 20). A higher occurrence of ARs is seen in people with hemiplegic cerebral palsy (CP) compared with people with normal development (8, 10). There has been a long-held belief that ARs are unnecessary movements and would interfere with activity in people with neurological conditions (4, 12, 15, 33) because ARs were considered to be a sign of a compensatory reorganization in the motor system after early unilateral brain injury (8, 7, 34).

However, some current studies have found no support for the general view that ARs interfere with activity (11, 23). In contrast to the general view, ARs may be helpful in symmetrical bilateral movements through compensatory motor system reorganisation (9). ARs involve involuntary movement which may occur in homonymous muscles (1) or heteronymous muscles (5, 20) of the affected limb when the unaffected limb is active. Depending on the timing of

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the ARs in various muscles, they may be correlated or uncorrelated to the movements of an active limb and the clinical effect may be different. Most previous studies of ARs in people with hemiplegic CP have used observation scales, such as recording the degree of movement through observation (8, 23, 34). The sensitive quantitative method can detect ARs that are not amply visible. No study to date was found to separate the correlated and uncorrelated components of ARs. In order to further measure ARs quantitatively in both upper limbs of CP and to provide a full spectrum of upper ability, subjects with hemiplegic and quadriplegic CP were investigated in this study.

The elbow joint was investigated because it is a common site of motor impairments, such as spasticity and contracture, and has been reported as contributing to the fragmentation underlying the abnormal reaching trajectories in people with CP (28, 30). A tracking task was chosen to examine the ARs because this laboratory model provides the requirements of everyday coordination which incorporates the need to rapidly swap from agonist to antagonist with spatial and temporal accuracy. For example, when one wants to pick up the toast from a plate and put it into mouth, one would need to transport one hand from the plate to mouth, which requires the coordination of elbow flexor and extensor. Therefore, the aims of the study were: [1] to examine ARs quantitatively in dominant and non-dominant limbs of people with hemiplegic and quadriplegic CP compared with people with normal development and [2] to examine whether the ARs were correlated to the upper limb ability.

Materials and Methods

Participants

Participants included in this study were eight years of age or older and had sufficient cognition and language skills to participate (16). Data were collected from twenty-three subjects with hemiplegic CP (H group), aged from 8 to 52 years (mean ± SD: 21y 8m ± 11y 10m), twelve subjects with quadriplegic CP (Q group), aged from 11 to 41 years (21y 5m ± 10y 3m) and twenty-two subjects with normal development (N group), aged from 8 to 42 years (21y 2m ± 10y 10m). Handedness of the participants was determined by the Edinburgh Handedness Inventory (27). The procedures were approved by the relevant institutional ethics committees. Written informed consent was obtained prior to data collection.

Experimental Setup and Clinical Evaluations

All of the measurements were non-invasive and the procedures have been employed previously by the investigators (26). Two main tests, tracking performance and clinical evaluations, administered in random order and with a minimum of a 10 min break between tests.

Experimental Setup

Electromyography (EMG) was recorded from biceps and triceps muscles of both arms using bipolar silver/silver chloride surface electrodes (3M Red Dot 2258-3, Sydney, Australia) positioned according to Basmajian and Blumenstein (2). The earth electrode was fixed at the olecranon of the ulna. All participants were then seated in high-backed chair between two height adjustable tables where their forearms were securely strapped into horizontal arm frames that kept the shoulders abducted to 90° and the elbow centred at 90° of flexion (Fig. 1A). Flexion and extension maximum voluntary isometric contractions (MVC) were measured for four seconds to be used for EMG normalization. Once the MVC measures were completed, the participants were given a break.

A unilateral upper limb visual pursuit position tracking task was employed (Fig. 1B). This task required the participants to coordinate their elbow flexors and extensors to skilfully vary the amplitude, speed and timing of their movements. HyperTrack™ software (SDR Clinical Technology, Sydney, Australia) was used to provide a visual tracking display on a 43-cm computer monitor (107E4, Phillips, Sydney, Australia) placed ~1 m in front of the participants. The participants were required to follow a horizontally moving target with a response cursor which they controlled *via* elbow flexion and extension for one minute per target. This task was performed by providing low friction arm frame, supporting of the weight of arm against gravity, and only requiring the elbow flexors/extensors to work in a range of 10 degrees. In this position, participants were only required to exert minimal strength (< 1 Nm elbow flexor/extensor torque) to perform the tracking task. Elbow angle was measured by a potentiometer aligned directly below the elbow joint. Moving the arm from left to the right moved the response cursor from left to right and vice versa. Rhythmic targets (sinusoids at a 0.1, 0.35 and 0.75 Hz) and irregular targets (broadband frequency at ranges 0-0.25 and 0-0.75 Hz) were employed. Both rhythmic and irregular targets were chosen in order to provide various degrees of difficulties for all participants. These targets were tracked with either the dominant or the non-dominant limb in randomized order. The tasks in this measurement were explained to the participants and the participants practiced one regular (sinusoidal 0.35 Hz) and one irregular target (broadband 0-0.25) for one minute prior to data collection. There were five

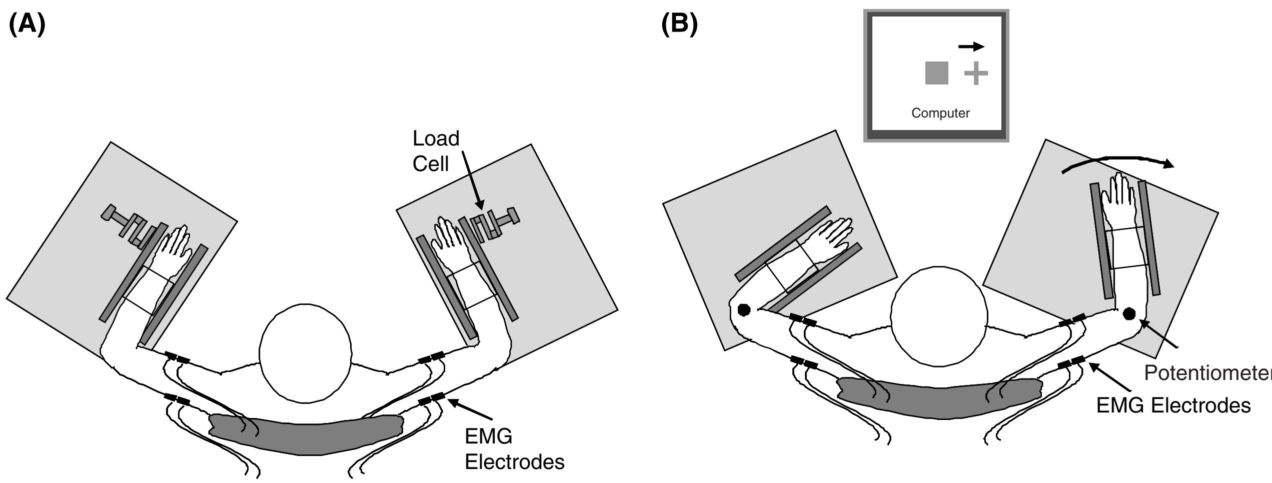

Fig. 1. The setup for (A) measuring muscle strength of biceps and triceps and (B) for tracking tasks showing target (square) and response (cross) cursors. Movement to the right moves the cursors to the right and vice versa.

targets and two tracking limbs totalling 10 trials collected for each participant. A minimum of one minute break was given to the participants between each target trial. Extra breaks were given to the participants as necessary.

Clinical Evaluations

Two separate clinical evaluations were obtained for each participant. The Quality of Upper Extremity Skills Test (QUEST) was developed to measure the quality of upper extremity movement in people with neuromotor dysfunction (13). Only Section A and B (upper limb performance) of QUEST were employed for the H and Q groups as the N group scored 100% on this test. The mean scores (Section A plus Section B) were calculated separately for dominant and non-dominant limbs to reflect their individual performance. The QUEST scores ranged between zero and 100%.

The Nine Hole Peg Test (9-HPT) is a simple timed test of upper limb activity (22). It requires the participant to place nine dowels in nine holes and then remove them all, the time taken being recorded. The score on 9-HPT was calculated as the average number of pegs per second in order to report the score in the direction of progressive increase, ranging from unable to perform the test [0] to very good [such as 0.54].

Data Acquisition and Analysis

EMG, torque signals and position signals were sampled synchronously by a 16-bit A-D converter (MP100A, BIOPAC Systems Inc., Sydney, Australia) at 2000 Hz and stored on a PC using the AcqKnowledge Software Package (Version 3.7.3, BIOPAC Systems Inc). A second 16-bit A-D converter (MP100A, BIOPAC Systems Inc) synchronized with the first was used to collect the target and position (response) signals at 100 Hz sample rate.

MATLAB (Version 7.0, The MathWorks Inc., Sydney, Australia) was used to process the data off-line. Integrated EMG data was obtained by high-pass filtering (8^{th}- order Butterworth zero lag) at 80 Hz, rectifying and then low-pass filtering the EMG data (8^{th}- order Butterworth zero lag) at 4 Hz. This cut-off frequency was chosen because all frequencies of interest were less than 4 Hz. The filtered EMG signals were normalized to the filtered maximum EMG from three trials using the following equation: (EMG-baseline)/(MVC-baseline) $\times$ 100%. The baseline EMG was an average of the filtered EMG over a 5 s window of rest.

ARs are the involuntary movement of one limb in response to contralateral active movement. Therefore, only data from unilateral upper limb visual pursuit position tracking were analysed. In order to provide quantitative measures of ARs, a cross-correlational and spectrographic analysis (3) was carried out between the position signals of both limbs during tracking. ARs were measured by the overall coherence and overall gain between the movements of the tracking and non-tracking limbs. Overall coherence (correlation ratio) and overall gain (amplitude ratio) are the similarity between the tracking and non-tracking limbs, where the score of overall coherence of 1 is perfect correlation between tracking and non-tracking limbs. The score of overall gain of 1 would mean that the amplitude of the movement of the non-tracking limb is equal to that of the tracking limb. The overall coherence measure is based on the coherence over all frequencies and so it is more reliable than the coherence at individual frequencies. The fact that the overall coherence is a statistical measure that is incorporated into another statistical procedure is no

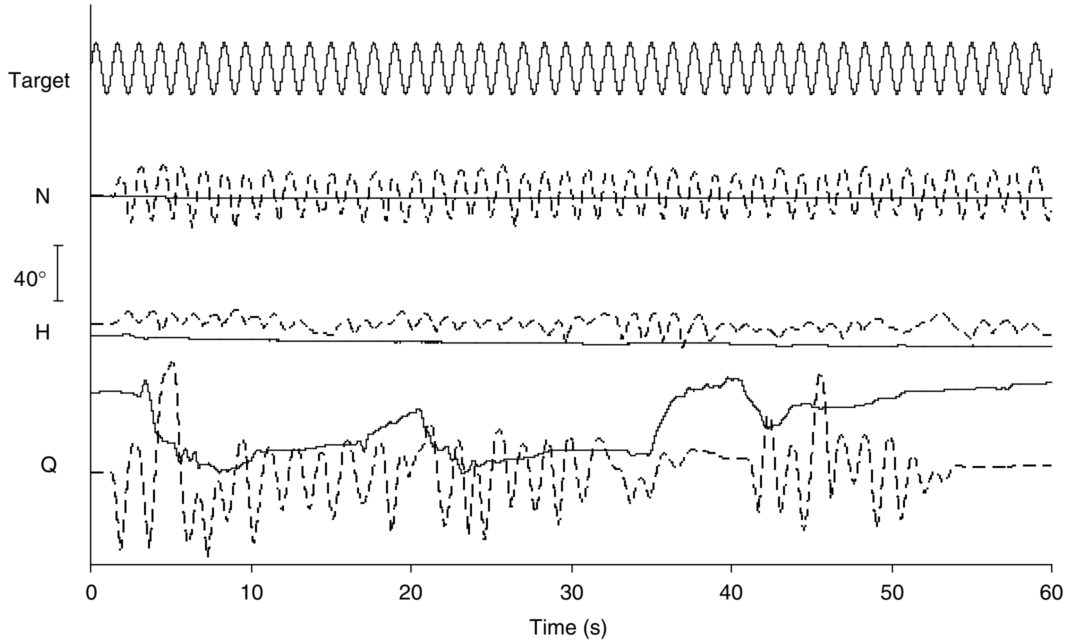

Fig. 2. One complete trial of tracking movement of non-dominant limb tracking (dashed line) at 0.75 Hz and ARs in the dominant limb (solid line) H: hemiplegia, Q: quadriplegia, N: normal.

different to using an outcome measure such as root mean square (RMS) error, which is an average computed over a one minute tracking trial; or to using a score such as IQ. Such individual measures based on a series of sub-tests are widely used as input to subsequent statistical tests on groups of individuals. The average amount of movement in each limb was calculated as the RMS of the elbow flexion angle movements in both the tracking and the non-tracking limbs (reported in °RMS). The amount of movement in the non-tracking limb that is correlated to the movement in the tracking limb was calculated by the amplitude of the zero mean elbow flexion angle of the tracking limb multiplied by the overall gain between the tracking and non-tracking limbs.

The data were checked using probability plots and found to be normally distributed. Variances were checked using Levene's Test and found to be homogeneous. Analysis of variance (ANOVA) was employed to examine the following factors: participant groups (two groups with cerebral palsy and control group), limb (dominant *vs.* non-dominant) and speed (sinusoidal at 0.1, 0.35 and 0.75 Hz; broadband at frequency ranges 0-0.25 and 0-0.75 Hz). A fourth factor, muscles (biceps *vs.* triceps), was included for the ANOVA used to analyse the muscle activity for all groups. *Post hoc* comparisons were performed using the Tukey HSD test. Significance level was set to 0.05. In addition, the relationship between age and overall coherence was examined by Pearson's correlation. Since the QUEST scores were non-parametric and the 9-HPT scores did not exhibit equal variances across groups or normality of the data, the QUEST scores of the two groups with cerebral palsy were compared with the Mann-Whitney U test and the 9-HPT scores of all three groups were compared with Kruskal-Wallis one way ANOVA. The relationships between the clinical evaluations and overall coherence and the amount of movement in the tracking limb not correlated to tracking were examined using Spearman's correlation.

Results

In this study, the movement in the non-tracking limb was found to be higher in the Q group, lower in the H group and minimal in the N group. Furthermore, the Q group had more movements in the non-tracking limb which were correlated to the tracking limb (Fig. 2).

The coherence between the tracking and non-tracking limbs during dominant tracking was not different among all three groups. During non-dominant limb tracking, however, the coherence was not significantly different between the H and Q groups, but the H and Q groups had a higher coherence than the N group ($F_{2,54} = 9.68$, $P < 0.01$) (Fig. 3). The difference between dominant and non-dominant limb tracking was in the H and Q groups where higher coherence was found during non-dominant limb tracking ($F_{2,54} = 6.68$, $P < 0.01$). There was no effect of speed on the coherence for the three groups ($F_{8,216}$ =

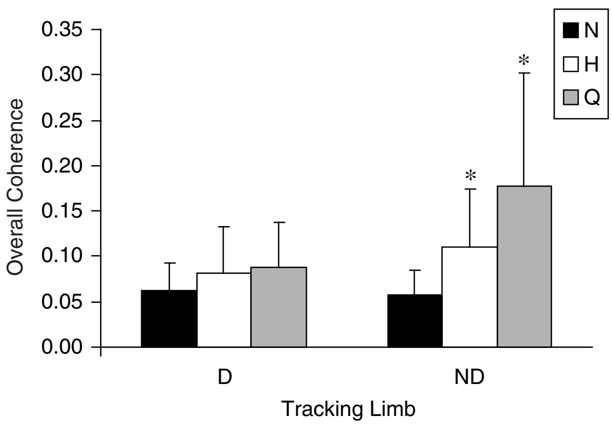

Fig. 3. The occurrence of ARs. Overall coherence (overall coherence was averaged across all speeds) between the tracking and non-tracking limbs during dominant (D) and non-dominant limb (ND) tracking. N: normal, H: hemiplegia, Q: quadriplegia. *significantly different ($P < 0.05$) to N group.

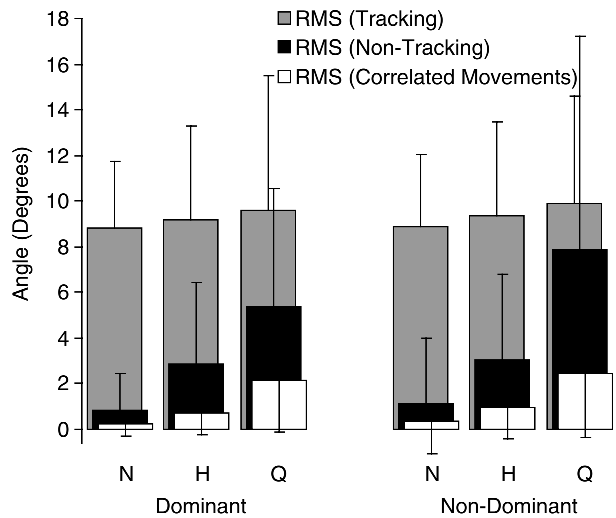

Fig. 4. The amplitude of joint movement (°RMS) - (amount of ARs). The mean and standard deviation of the amplitude of movement as measured in °RMS of the elbow flexion angle of the tracking (grey bar) and non-tracking (black bar) limbs as well as the amount of movement in the non-tracking limb correlated to the tracking limb (white bar) for all groups. N: normal, H: hemiplegia, Q: quadriplegia.

1.08, $P = 0.38$).

The amplitude of the movement (°RMS) of the tracking limb was not different among all groups ($F_{2,54} = 0.71$, $P = 0.50$). The amplitude of the movement of the non-tracking limb was larger in the Q group than the H and N groups ($F_{2,54} = 15.37$, $P < 0.001$) with no significant differences between the H and N groups. The amplitude of the movement of the non-tracking limb was higher during non-dominant than dominant tracking in all three groups ($F_{1,54} = 4.58$, $P = 0.04$). There was no effect of speed on the amplitude of the movement of non-tracking limb for the three groups ($F_{4,216} = 1.0$, $P = 0.41$).

The analysis indicated that there were movements that were correlated with the tracking limb and movements that were not correlated with the tracking limb. The correlated ARs were defined as the movement of the non-tracking limb that were correlated to the tracking limb and the uncorrelated ARs were the movements of the non-tracking limb that were uncorrelated to the tracking limb. The correlated ARs were larger in the Q group than the H and N groups ($F_{2,54} = 19.00$, $P < 0.001$) with no significant differences between the H and N groups. The proportion of the correlated ARs for the dominant and non-dominant tracking in the N group was 26% and 29% respectively, in the H group was 24% and 31% and in the Q group was 39% and 31% (Fig. 4).

There was no difference found between the level of EMG in biceps and triceps of both tracking ($F_{2,54} = 0.27$, $P = 0.77$) and non-tracking limbs ($F_{2,54} = 0.76$, $P = 0.71$) for all groups. The Q group had higher levels of EMG activity, in both biceps and triceps muscle, than both the H and N groups, which were similar in non-tracking limbs during both dominant and non-dominant limb tracking ($F_{2,54} > 9.02$, $P < 0.001$) (Fig. 5).

The level of EMG of the non-tracking limb was similar between dominant and non-dominant limbs in the H and N groups for both dominant and non-dominant limb tracking while the Q group had more muscle activity in the non-dominant limb during dominant limb tracking than the dominant limb during non-dominant limb tracking ($F_{2,54} = 7.92$, $P < 0.001$).

The performance in the 9-HPT in the N group was better than the H and Q groups in both the dominant and non-dominant limbs ($H_{2,57} \geq 33.13$, $P < 0.001$). The H group was better than the Q group in only the dominant limb ($H_{2,57} = 33.13$, $P = 0.001$) but not different in the non-dominant limb ($H_{2,57} = 37.02$, $P = 0.82$). The H group performed better than the Q group in the QUEST for both dominant and non dominant limbs ($U \geq 12.5$, $P < 0.001$). There was a high correlation between the 9-HPT and the QUEST scores (rho = 0.80, $P < 0.05$).

As overall coherence did not differ among speeds, the overall coherence was averaged across all speeds to examine the correlation with clinical evaluations. The relationship between the two clinical evaluations and overall coherence is displayed in Fig. 6. Overall coherence was negatively correlated with the 9-HPT during dominant (rho = -0.26, $P < 0.05$) and non-dominant limb tracking (rho = -0.35, $P < 0.05$), but not with the QUEST during either dominant or non-dominant limb tracking (rho < -0.04,

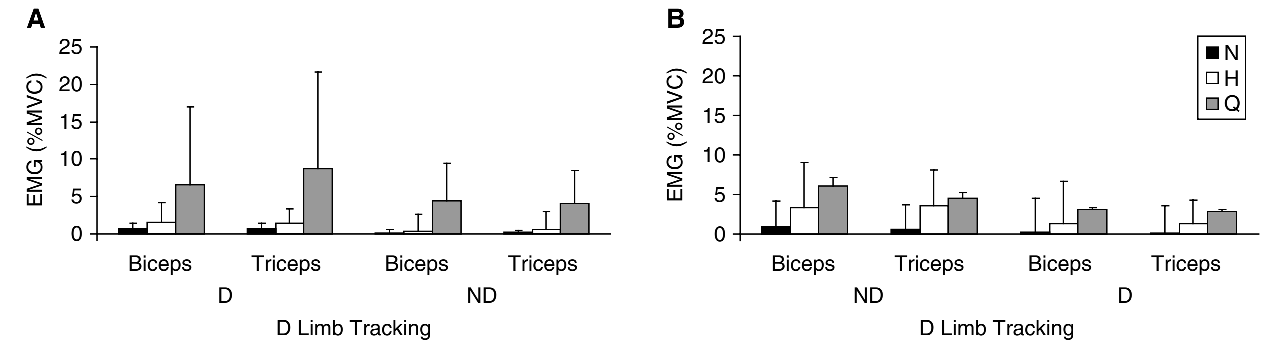

Fig. 5. EMG in biceps and triceps during A) dominant (D) limb tracking B) non-dominant (ND) limb tracking. N: normal, H: hemiplegia, Q: quadriplegia.

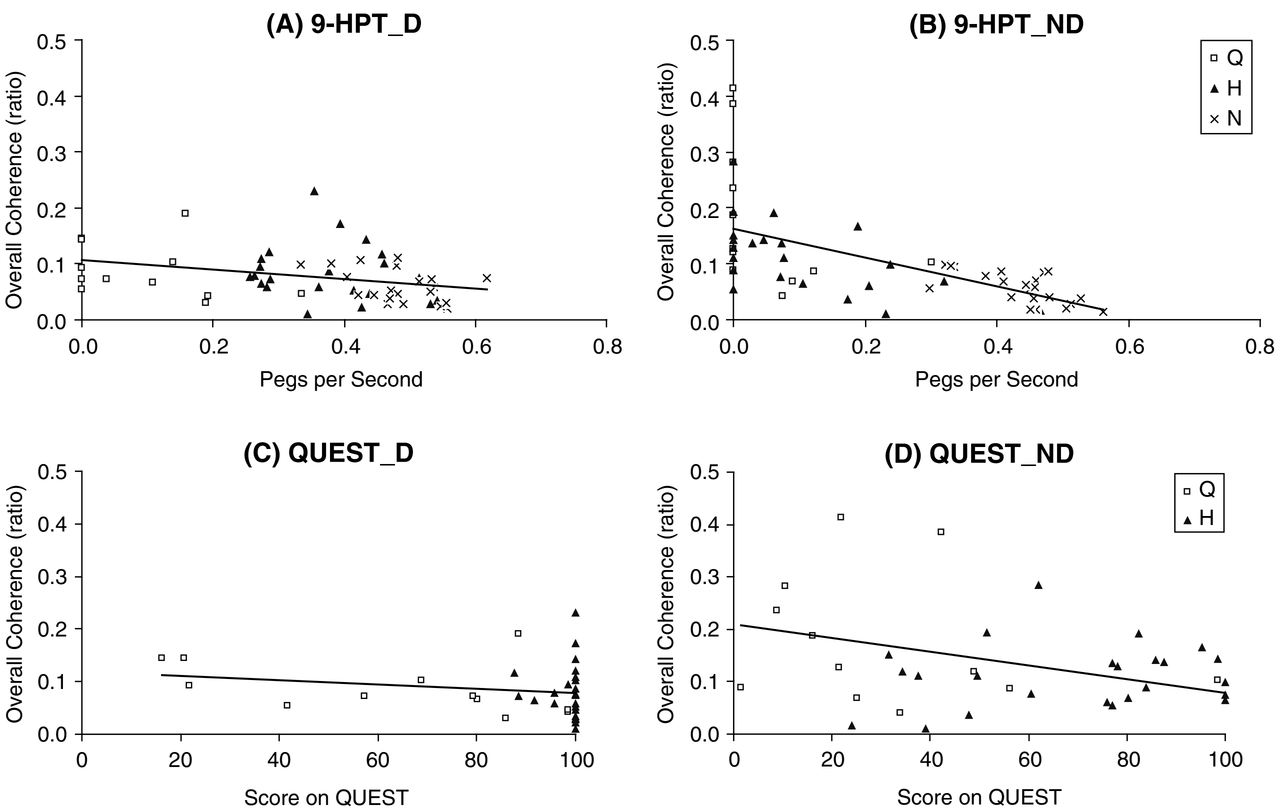

Fig. 6. The relationships between the occurrence of ARs (overall coherence) and 9-HPT (A and B) and QUEST (C and D). H: hemiplegia, Q: quadriplegia, N: normal, D: dominant limb tracking, ND: non-dominant limb tracking.

$P > 0.05$). There was no significant relationship between overall coherence and age in both dominant and non-dominant limbs for all three groups ($r < 0.38$, $P > 0.05$).

Correlated ARs were negatively correlated with the 9-HPT during dominant ($rho = -0.54$, $P < 0.05$) and non-dominant limb tracking ($rho = -0.68$, $P < 0.05$), with the QUEST during non-dominant limb tracking ($rho = -0.52$, $P < 0.05$), but not with the QUEST during dominant limb tracking ($rho = -0.08$, $P > 0.05$) (Fig. 7). There was no significant relationship between correlated ARs and age in both dominant and non-dominant limbs for all three groups ($r < -0.14$, $P > 0.05$).

Uncorrelated ARs were positively correlated with the 9-HPT during dominant ($rho = 0.55$, $P < 0.05$) and non-dominant limb tracking ($rho = 0.62$, $P < 0.05$) with the QUEST during non-dominant limb tracking ($rho = 0.52$, $P < 0.05$) but not with the QUEST during dominant limb tracking ($rho = 0.17$, $P > 0.05$) (Fig. 8). There was no significant relationship between uncorrelated ARs and age in both

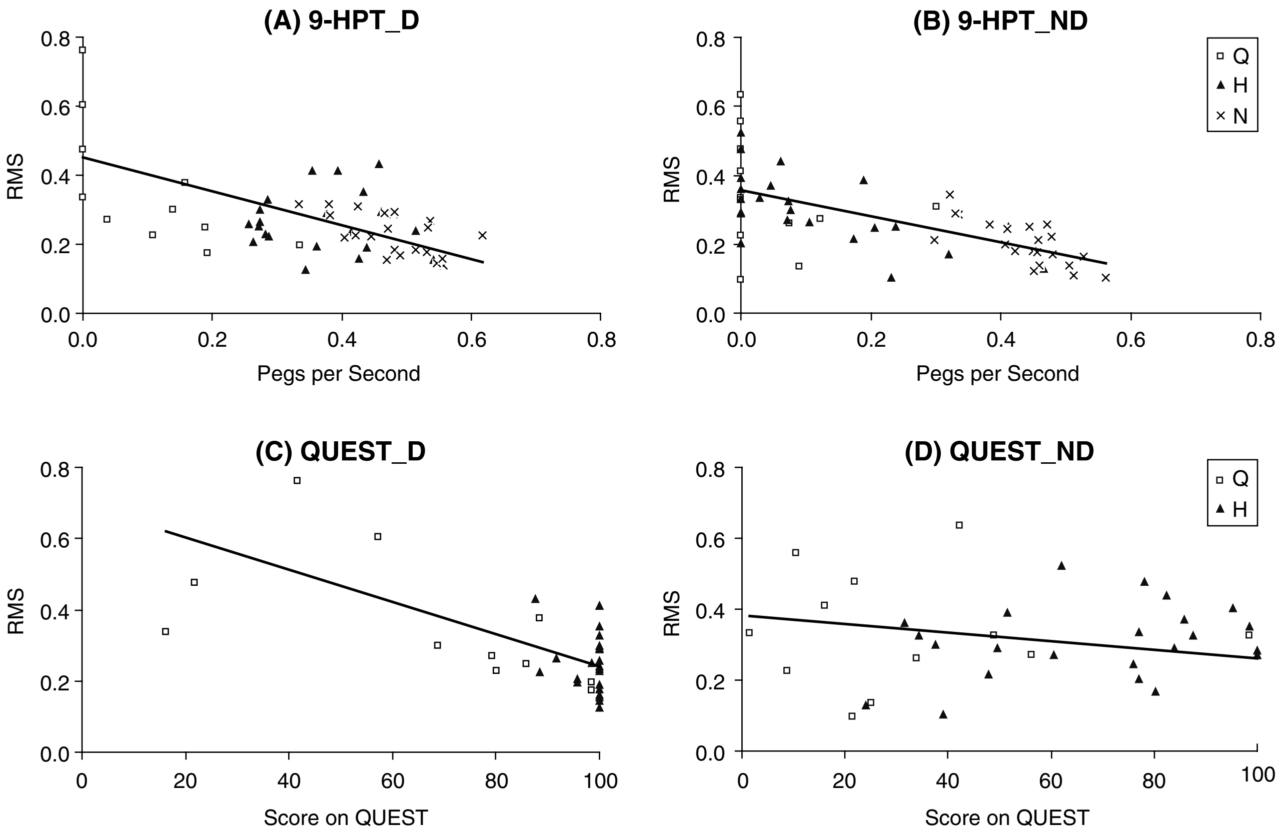

Fig. 7. The relationships between the amount of correlated ARs (RMS of the non-tracking correlated to tracking limb) and 9-HPT (A and B) and QUEST (C and D). H: hemiplegia, Q: quadriplegia, N: normal, D: dominant limb tracking, ND: non-dominant limb tracking.

dominant and non-dominant limbs for all three groups ($r < 0.17$, $P > 0.05$).

Discussion

An increased in both overall coherence and amount of ARs was found in both limbs of the Q group compared to the H and N groups. Furthermore, increased muscle activity in both limbs of the Q group was found in both tracking and non-tracking limbs. The quantitative data show that the amount of ARs in one limb could be correlated and uncorrelated to the contralateral limb. The correlated and uncorrelated ARs appear to have different relationships with clinical evaluations, implying the effect of ARs on upper limb activities could be varied.

The H and Q groups exhibited more correlated ARs as measured by overall coherence than the N group during non-dominant limb tracking. The H and Q groups had higher correlated ARs during non-dominant (affected) limb than dominant limb (unaffected) tracking. This is in line with previous studies (23, 34) which showed a high level of ARs in the unaffected limb while the more affected limb was active in people with hemiplegic CP. One possibility could be that the H and Q groups with more severely affected limbs may use the unaffected limb to facilitate the performance of the affected limb. This situation can be observed in people without neurological conditions when they are performing strenuous tasks (10, 21, 25), but it occurs more frequently in people with CP (7).

In the clinical situation, when people with hemiplegic CP are required to perform difficult tasks by using their affected hand, they utilize the unaffected hand to perform identical movement to assist the affected hand. Therefore, the ARs in the unaffected limb could have a positive influence on the affected limb. The unaffected limb could be used as a template for the affected limb for performing movements. This is in agreement with one previous study in children with hemiplegic CP (17): performing several lifts with one hand before lifting with the non-exercised hand led to force rates in the non-exercised hand that appropriately reflected the object's weight.

The overall coherence between limbs and amount of ARs demonstrated an inverse correlation with the 9-HPT which indicated that people who had poorer performance in the 9-HPT demonstrated a higher occurrence of ARs. This result is in line with a

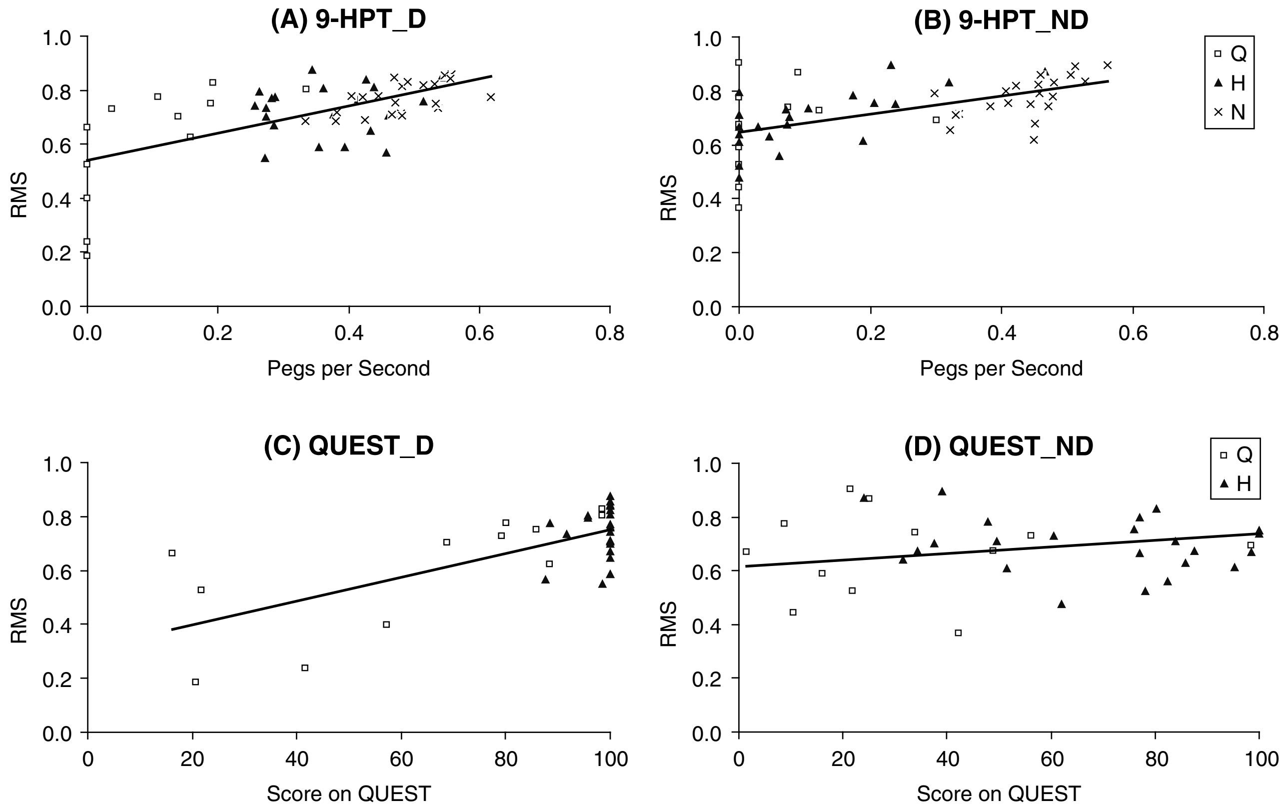

Fig. 8. The relationships between the amount of uncorrelated ARs (RMS of the non-tracking limb uncorrelated to tracking limb) and 9-HPT (A and B) and QUEST (C and D). H: hemiplegia, Q: quadriplegia, N: normal, D: dominant limb tracking, ND: non-dominant limb tracking.

previous study on children with normal development (24) which reported that the better the performance of the unimanual movement, the lower the occurrence of associated movements. The relationship found between the 9-HPT and the overall coherence between limbs and the lack of a relationship between the QUEST and the overall coherence between limbs implies that the measurement of the 9-HPT can reflect the performance of upper limb activity better than the QUEST. This could be because the 9-HPT reflects both the quantity (speed) and quality (accuracy) of a person's movement, while the QUEST merely examines isolated movements.

However, it is noteworthy that the amount of correlated ARs in the non-tracking limb was less than 40% for all three groups. Generally, people with normal development show ARs only in response to perform strenuous tasks (21), yet people with normal development had small amount of ARs in the current study, implying that these simple tracking tasks have small degrees of difficulty. This is in the line with our findings which showed that ARs in people with hemiplegic CP appeared to be an expression of spasticity and the magnitude was small and did not appear to influence coordination, but it is possible that larger ARs may hamper activities (11). On the other hand, this result indicates that the majority of the ARs were extraneous movements that were unrelated to the tracking limb. Surprisingly, the correlated ARs demonstrated a negative relationship with the 9-HPT performance while the uncorrelated ARs demonstrated a positive correlation with the 9-HPT. This relationship was also found in the QUEST. This is supported by that ARs interfered with hand activity during non-symmetrical bilateral movements (23), but contrast to that ARs could be helpful in symmetrical bilateral movements (32).

Carr *et al.* (8) and Kuhtz-Buschbeck *et al.* (23) reported that larger ARs in children and adults with hemiplegic CP did not interfere with hand activity. Carr *et al.* (8) investigated central nervous system reorganization using magnetic stimulation of the affected brain hemisphere where severity of damage was indicated by failure to evoke contractions of hand muscles. Compensatory corticospinal pathways with branching axons derived from the less damaged hemisphere were found. This is consistent with some review studies suggesting that there are some potential bilateral interactions in various brain regions (9, 19). ARs, therefore, appeared to enhance neural activity and indicated functionally efficient reorganization. This is consistent with our results for uncorrelated ARs, which have a positive relationship with clinical evaluations, while correlated ARs are negatively correlated to clinical evaluations implying that correlated ARs may be an indicator of limb impairment.

In the current study, the muscle activation levels of only the biceps were recorded. It is not known whether the other muscles around the wrist and elbow are contracting and to what extent. It is possible that in the three groups, the other muscle exhibited different levels of ARs. It is recommended that future studies are recorded from these muscles to comprehensively evaluate the levels of ARs in the three groups.

There has been a long-held belief that ARs are unnecessary movements and would interfere with activity (4, 12, 15, 33). Although our work showed that tasks with non-dominant limb tracking had a higher frequency of ARs in CP, that is, more difficulties in the control of upper limb coordination were observed in the more impaired limb, these ARs did not interfere in the task that was tested and even uncorrelated ARs have positive a relationship with clinical evaluations.

As successful performance of everyday tasks requires upper limb coordination in changing environmental situations, such coordination would be required to modify movements in order to maintain successful performance when the tasks have some difficulties. Since these ARs did not interfere with clinical performance, the results from this study suggest that tasks which involve interaction with objects or people in motion could be considered, including reaching to retrieve a moving or falling object, such as throwhead-catch practice, and more advanced sports (cricket, soccer, basketball, billiard, golf and snooker). This kind of task-specific training was developed by Carr and Shepherd (6) and is now commonly used in children and adults with hemiplegia. These tasks, which are relevant to skills instead of practising meaningless movements, would enhance the quality of upper limb activity (31). Tasks also can involve more fine skills, such as playing musical instruments (piano, guitar, and keyboard), and combine enhanced feedback techniques which may have the potential to further augment gains in coordination (14), such as computer games, Wii Sports. Furthermore, interactive computer play has been proposed to be a potentially promising method to produce positive effects on the upper limb coordination in people with CP (29). Therefore, these findings suggest that with intensive practice both symmetrical bilateral movements and non-symmetrical bilateral movements may be beneficial for reducing activity limitation (18).

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