



Contra-Lateral Unintended Upper Arm Movement during Unimanual Tasks in Children with Cerebral Palsy

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Purpose: To characterize associated reactions (ARs) in the contralateral arm across multiple muscles during unimanual tasks and to identify factors related to ARs in children with cerebral palsy (CP).

Materials and Methods: This was a prospective, cross-sectional study of 35 children with CP. The extent of ARs of the contra-lateral, non-task hand was assessed while performing three unimanual tasks (opening and clenching the fist, a finger opposition task, and tapping fingers). The occurrence of ARs in each trial was evaluated separately for each task using a four-point scale (total scores ranged from 0 to 12). Surface electromyography (SEMG) was used to measure the firing activity of the muscles of the opposite arm during the task. The Manual Ability Classification System and Melbourne Assessment 2 (MA-2) were used to evaluate upper limb function.

Results: AR scores were higher in the more-affected limb than in the less-affected limb. SEMG data on the non-task hand showed motor overflow up to the elbow muscles in the more-affected limb. Root mean square ratios of EMG signals were significantly higher in children with ARs than in children without ARs. Multiple regression analysis showed both age and MA-2 to be significant factors related to ARs in the more-affected limb.

Conclusion: Children with visible ARs showed motor overflow in the non-task limb during unimanual hand tasks. Age and upper limb function were significantly related to the extent of ARs in the more-affected limb of children with CP.

Key Words: Cerebral palsy, associated reaction, upper limb function

INTRODUCTION

Cerebral palsy (CP) is the most common motor disability in children, and 0.25% of total neonates are diagnosed with CP in Ko-

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rea.¹ Associated reactions (ARs) and mirror movements (MMs) are common motor dysfunctions in children with CP.² While AR and MM have been used interchangeably to describe unintended motions in the non-task hand, AR is characterized as involuntary movement in non-homologous muscles, either contralaterally or ipsilaterally,^{3,4} whereas MM comprises simultaneous involuntary movements of homologous muscles on the contralateral side of the body that accompany voluntary movement.⁵

Although ARs are considered to be a normal feature of motor behavior in young children due to immaturity of their central nervous system,^{6,7} they are considered to be pathological if pronounced and persistent.² It has been suggested that white matter abnormalities in motor/premotor circuits are responsible for pathologic AR.⁴ In general, AR is thought to be associated with impaired upper limb function, especially in bimanual activities.^{5,7-9} However, the association between AR and unimanu-

al function in children with CP still remains inconclusive.^{2,5,7-10} Some researchers have reported no significant relation between them,^{2,5} whereas others have demonstrated significant associations in both hands^{5,7,9,10} or only in the non-paretic hand.⁸

This study aimed to characterize unintended contralateral upper arm movement with surface electromyography (SEMG) of multiple muscles during unimanual tasks and to identify factors related with AR in children with CP.

MATERIALS AND METHODS

Participants

This prospective, cross-sectional, observational study was conducted at a university-affiliated, tertiary-care hospital. Children with CP, who were admitted to our hospital for intensive therapy between March 2017 and November 2017, were consecutively screened for inclusion and exclusion criteria. The inclusion criteria were as follows: 1) Manual Ability Classification System (MACS) I (handles objects easily and successfully) to IV (handles a limited selection of easily managed objects in adapted situations), 2) age between 4 and 18 years, and 3) child and/or primary caregiver of the child agreed to participate in this study. Exclusion criteria were 1) inability to understand and follow commands, 2) chemodeneration therapy in upper extremities within 6 months, 3) previous orthopedic surgery in the upper limb within 1 year, and 4) changes in antiepileptic drugs or in medicines for hypertonia, or in their dosages, within 6 months.

The Institutional Review Board (IRB) of Severance Hospital approved this study protocol (approval number: 4-2016-0006). Informed consent was obtained from the primary caregiver and/or the participant, according to IRB rules.

Clinical assessments

For each child, Gross Motor Function Classification System-Expanded & Revised (GMFCS-E&R) and MACS functional levels were determined according to their instruction manuals by one of the authors (Park HK) with 5 years of experience in managing children with CP. GMFCS is used to categorize gross motor function in children with CP into five different levels, with emphasis on sitting, transfers, and mobility. MACS is considered a standard classification system for manual ability in children with CP, and it classifies how children with CP use their hands to do daily activities across five different levels.¹¹ MACS assesses the collaboration of both hands; however, it does not assess the function of each hand separately. In this study, GMFCS or MACS levels of I or II were defined as good functioning, while other levels were defined as poor functioning. The Melbourne Assessment of Unilateral Upper Limb Function (MUUL) is a reliable and valid tool for measuring upper limb function, and it has been increasingly used as an outcome measure in children with CP.^{12,13} MUUL was revised to Melbourne Assessment 2 (MA-2) in an effort to increase uni-dimensionality of the to-

tal scale of the original version through Rasch analysis. MA-2 comprises 14 tasks and 30 movement scores grouped across four separate subscales.¹³ In this study, MA-2 was administered by an occupational therapist who had more than 5 years of experience in managing children with CP.

Associated reaction scoring

Each patient was comfortably seated in a chair, with both arms placed on a table. The children performed three unimanual activities: Task 1, opening and clenching the fist; Task 2, a finger opposition task; and Task 3, tapping fingers on the table surface. Each task was repeated five times for each hand, first with the less-affected hand and then with the more-affected hand. The intensity of visible ARs was assessed according to the method used in previous studies.^{5,14} The participants were videotaped (50 frames per second). The occurrence of ARs in each trial was evaluated separately for each task using a four-point scale: 0, no clear imitative movement; 1, barely discernable repetitive movements; 2, slight MM or stronger, but briefer repetitive movements; 3, strong and sustained repetitive movements; and 4, movements equal to those expected for the intended hand.¹⁵ The highest score in trials for each task was selected as the score of each task. Total possible scores ranged from 0 to 12. Videos were scored by a physiatrist (Park HK). For each task, if the score was more than 2, it is defined as AR positive in the AR subscale;¹⁴ in this study, visible AR was defined as a total score ≥ 4 .

Surface electromyography

For SEMG recording, each patient was comfortably seated in a chair, with both arms on the table surface. While children performed three tasks with one hand, the muscle activities of the contra-lateral shoulder abductor, elbow flexor, elbow extensor, wrist flexor, and wrist extensor muscles were recorded using surface electrodes. Five consecutive trials were performed in each task. Prior to electrode attachment, the skin was rubbed with alcohol, and skin resistance was kept below 5 k Ω . Active electrodes were attached to the belly of the shoulder abductor, elbow flexor, elbow extensor, wrist flexor, and wrist extensor muscles. The reference electrode was placed at the olecranon process. A multi-channel EMG system (MA 300 DTU, Motion Lab Systems, Inc., Baton Rouge, LA, USA) was used to record and analyze EMG data. The band pass filter was set at 20 Hz to 500 Hz. EMG signals were captured at a 1000-Hz sampling frequency. EMG data were transferred to a personal computer after the end of measurement, and were further processed by Matlab software (MathWorks, Inc., Natick, MA, USA). All EMG signals of the five consecutive trials of each task were rectified and integrated. EMG signals in each task were divided into 16 time intervals, and the root mean square (RMS) values of each interval were computed using "rms" Matlab software. We set a baseline period as intervals in which the lowest RMS value appeared continuously in two or more of the 16 intervals, and an

active period was set as intervals in which the values were larger than the baseline period. The mean RMS values during the active and baseline periods were assessed. Then, the ratios between active RMS and baseline RMS values were calculated.

Statistical analysis

Since the data were not normally distributed, the Mann-Whitney U-test was used to investigate differences in continuous variables between age groups and MACS groups, and the Wilcoxon rank sum test was used to compare the more- and less-affected sides. Fisher's exact test was used to compare differences in the distributions of functional levels and in the incidence of visible AR between groups due to the small expected cell sizes. Spearman correlation analysis was used to investigate correlations between clinical AR scores and other variables, such as age, MA-2, and RMS ratios of SEMG. Significant variables, except for confounding variables, entered multiple regression analysis to analyze factors associated with scores of clinical AR. Spearman's correlation ≥ 0.80 was defined as very strong, 0.80–0.60 as strong, 0.60–0.40 as moderate, 0.40–0.20 as weak, and 0.20 as very weak.¹⁶ All statistical analyses were conducted with SPSS version 25 for Windows (IBM Corp., Armonk, NY, USA), and p -value < 0.05 was considered statistically significant.

RESULTS

Thirty-five children with spastic CP (21 unilateral CP and 14 bilateral CP; 21 boys and 14 girls) were recruited in this study. SEMG data were not available for six children due to poor cooperation throughout the procedures. The mean age of the subjects was 9.6 years (± 3.7), ranging from 4 to 16 years. The children were at GMFCS level I to IV (8/13/8/6) and MACS I to IV (7/15/8/5). MA-2 scores were significantly lower in the more-affected side than in the less-affected side ($p < 0.001$). Grouping the children into two groups of young children (age < 9 years) and older children (age ≥ 9 years), we noted that the median age (interquartile range) of the young group was 5.8 years (2.4), whereas that of the older group was 12.4 years (2.9). There was no significant difference in demographic characteristics, including gender, GMFCS and MACS levels, and MA-2, between the young and older groups (Table 1).

Visible AR (total AR score ≥ 4) in the more-affected limb was noted in 20 (57.1%) children, whereas it was noted in 11 (31.4%) children in the less-affected limb. Positive AR (AR subscore ≥ 2) was significantly more common on the more-affected side than on the less-affected side during Tasks 1 and 3 ($p = 0.030$, $p = 0.036$, respectively). The mean total scores of AR were significantly higher in the more-affected limb than in the less-affected limb ($p < 0.001$) (Table 2).

Visible AR in the more-affected limb was more frequently observed in the low functioning group in regards to manual ability (MACS III to IV) than in the high functioning group ($p =$

Table 1. Characteristics of the Participants

	Total CP (n=35)	Young children (age<9) (n=16)	Older children (age≥9) (n=19)	<i>p</i> value
Age (yr)	9.5 (7.2)	5.8 (2.4)	12.4 (2.9)	<0.001
Gender, n (%)				>0.999
Male	21 (60.0)	10 (62.5)	11 (57.9)	
Female	14 (40.0)	6 (37.5)	8 (42.1)	
Type, n (%)				0.166
Unilateral	21 (60.0)	12 (75.0)	9 (47.4)	
Bilateral	14 (40.0)	4 (25.0)	10 (52.6)	
GMFCS, n (%)				0.491
I–II	21 (60.0)	11 (68.8)	10 (52.6)	
III–IV	14 (40.0)	5 (31.3)	9 (47.4)	
MACS, n (%)				0.503
I–II	22 (62.9)	9 (56.3)	13 (68.4)	
III–IV	13 (37.1)	7 (43.8)	6 (31.6)	
MA-2, median (interquartile range)				
More-affected side				
ROM	85.2 (40.7)*	85.2 (34.2)	88.9 (44.4)	0.433
Fluency	100.0 (20.0)*	98.0 (32.0)	100.0 (12.0)	0.612
Accuracy	87.5 (37.5)*	84.4 (46.8)	87.5 (43.7)	0.414
Dexterity	71.4 (57.2)*	64.3 (45.2)	76.2 (57.2)	0.584
Average	85.5 (38.2)*	83.2 (36.0)	90.7 (39.5)	0.312
Less-affected side				
ROM	96.3 (11.1)	96.3 (13.9)	100.0 (11.1)	0.180
Fluency	100.0 (0.0)	100.0 (0.0)	100.0 (0.0)	0.433
Accuracy	94.7 (10.5)	94.7 (14.5)	94.7 (10.5)	0.434
Dexterity	90.5 (23.8)	95.2 (20.2)	85.7 (28.6)	0.789
Average	95.4 (11.1)	95.7 (11.4)	95.1 (11.2)	0.740

CP, cerebral palsy; GMFCS, Gross Motor Function Classification System; MACS, Manual Ability Classification System; MA-2, Melbourne Assessment 2; ROM, range of motion.

Values are presented as a median (interquartile range) unless otherwise noticed. * $p < 0.001$, compared to the less-affected side in the total CP group and based on Wilcoxon signed rank test.

0.002), although this difference in visible AR in the more-affected limb was not significant for differences in gross motor function (GMFCS III to IV). In the less-affected limb, there was a significant difference in frequency of visible AR in low functioning groups on both manual ability and gross motor function ($p = 0.007$, $p = 0.011$, respectively). Children with visible AR in the more-affected upper limb had significantly lower MA-2 scores than children without AR. However, there were no significant differences in MA-2 scores in the less-affected upper limb according to presence of visible AR, except for dexterity (Table 3).

Muscle activities increased during trials of each task from baseline activity at resting status in the limb with visible AR (Fig. 1). RMS ratios were significantly higher in some muscles of the more-affected upper arm when performing tasks with the less-affected limb. For the more-affected limb, RMS ratios of the elbow flexor and extensor for Task 1 ($p = 0.034$, $p = 0.004$, respectively) and elbow extensor and wrist extensor for Task 3

($p=0.046$, $p=0.025$, respectively) were significantly higher in the group with visible AR, compared to the group without visible AR. For the less-affected limb, children with visible AR had significantly larger RMS ratios in the wrist flexor during Task 1 without any significant differences during other tasks, compared to the group without visible AR ($p=0.005$). The average total RMS ratios of the three tasks did not show significant dif-

ferences between groups with and without visible AR on either the more- or less-affected side (Table 4).

Visible AR in the more-affected limb was significantly more common in the young children group than in the older children group ($p=0.002$). However, the presence of visible AR in the less-affected limb was not significantly different between the young and older children groups. The total scores of AR in the more-affected limb were significantly higher in the young children group than in the older children group ($p=0.003$), whereas total AR scores in the less-affected limb were not significantly different. Children in the high functioning group of manual ability (MACS I-II) had significantly higher MA-2 scores and lower AR total scores in both the more-affected and less-affected limbs (Table 5).

Visible AR in the more-affected limb was noted in 17 (81 %) children with unilateral CP, whereas it was noted in only nine (42.9%) children in the less-affected limb. Visible AR was significantly more common on the more-affected side than on the less-affected side in children with unilateral CP ($p=0.011$). Visible AR of the more-affected upper limb was significantly more common in children with unilateral CP than in children with bilateral CP ($p<0.001$), although there was no significant difference in frequency of visible AR in the less-affected limb between children with unilateral and bilateral CP. The mean scores of AR were significantly higher in the more-affected limb than in the less-affected limb only in children with unilateral CP.

AR scores in the more-affected upper limb showed a strong association with MA-2 score ($\rho=-0.700$, $p<0.001$) and moderate relationships with the ratio of RMS ($\rho=0.476$, $p=0.012$) and age ($\rho=-0.471$, $p=0.004$), whereas AR scores in the less-affected limb showed only moderate association with MA-2 score ($\rho=-0.414$, $p=0.013$). Multiple regression analysis revealed that age and

Table 2. Comparison of Visible AR Frequencies and AR Scores

	More-affected side	Less-affected side	p value
Task 1			
AR (+)	14 (40.0)	5 (14.3)	0.030*
AR (-)	21 (60.0)	30 (85.7)	
Score	1.5±1.5	0.7±0.9	0.001 [†]
Task 2			
AR (+)	21 (60.0)	12 (34.3)	0.055*
AR (-)	14 (40.0)	23 (65.7)	
Score	1.7±1.4	1.1±1.1	0.001 [†]
Task 3			
AR (+)	15 (42.9)	6 (17.1)	0.036*
AR (-)	20 (57.1)	29 (82.9)	
Score	1.3±1.3	0.6±0.9	0.001 [†]
Total			
AR (+)	20 (57.1)	11 (31.4)	0.053*
AR (-)	15 (42.9)	24 (68.6)	
Score	4.5±3.8	2.4±2.5	<0.001 [†]

AR, associated reaction. Values are presented as a number (%) or mean±standard deviation. Task 1, opening and clenching the fist; Task 2, a finger opposition task; Task 3, tapping fingers on the table surface. *Comparison of AR frequency with side based on Fisher's exact test, [†]Comparison of AR score with side based on Wilcoxon signed rank test.

Table 3. Comparison of AR Frequencies between Good and Less Functioning Groups and Comparison of Upper Arm Function between Groups with and without AR

	More-affected side		p value	Less-affected side		p value
	AR (+) (n=20)	AR (-) (n=15)		AR (+) (n=11)	AR (-) (n=24)	
GMFCS			0.728			0.011*
I-II	11 (55.0)	10 (66.7)		3 (27.3)	18 (75.0)	
III-IV	9 (45.0)	5 (33.3)		8 (72.7)	6 (25.0)	
MACS			0.002*			0.007*
I-II	8 (40.0)	14 (93.3)		3 (27.3)	19 (79.2)	
III-IV	12 (60.0)	1 (6.7)		8 (72.7)	5 (20.8)	
MA-2						
ROM	65.19±28.23	88.65±14.22	0.007 [†]	89.24±11.4	95.53±6.27	0.111
Fluency	80.60±24.36	98.13±3.66	0.018 [†]	97.09±9.65	99.67±1.13	0.691
Accuracy	61.54±31.50	87.58±16.22	0.007 [†]	91.33±12.27	94.50±6.86	0.550
Dexterity	54.05±28.24	79.68±21.41	0.008 [†]	76.62±18.24	89.48±11.31	0.013 [†]
Average	65.34±27.01	88.51±13.36	0.005 [†]	88.57±11.71	94.8±5.37	0.065

AR, associated reaction; GMFCS, Gross Motor Function Classification System; MACS, Manual Ability Classification System; MA-2, Melbourne Assessment 2; ROM, range of motion. Values are presented as a number (%) or mean±standard deviation. * $p<0.05$ of GMFCS and MACS based on Fisher exact test, [†] $p<0.05$ of MA-2 based on Mann-Whitney U-test.

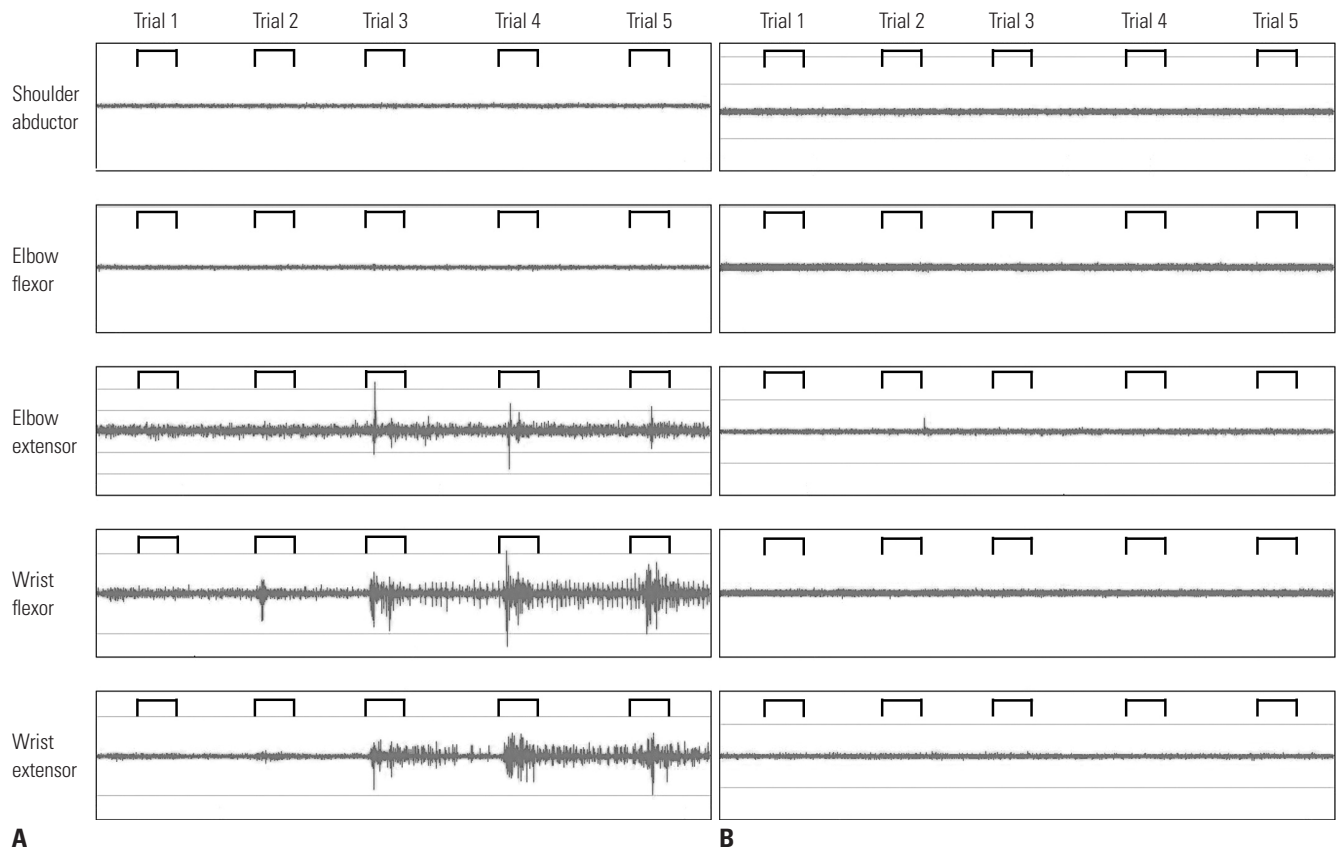


Fig. 1. Muscle activity of the upper limb on surface EMG during rest and five trials of Task 1 with the opposite hand in two children with unilateral CP. (A) Visible AR (+): muscle activities of the elbow extensor, wrist flexor, and wrist extensor in the more-affected side increased during tasks with the less-affected hand, compared to baseline activities at rest. (B) Visible AR (-): muscle activities of the upper limb in the less-affected side during tasks with the more-affected hand did not increase, compared to baseline activities at rest. CP, cerebral palsy; AR, associated reaction.

MA-2 were significant factors associated with AR scores in the more-affected hand ($p=0.010$, $p=0.002$, respectively), whereas no factor was associated with AR scores in the less-affected hand. Also, the standardized beta of MA-2 was larger than that of age in the more-affected side, with negative values (Table 6).

DISCUSSION

In this study, AR was assessed using a clinical tool and SEMG in multiple muscles, and we found motor overflow up to the elbow muscles of the non-task hand depending on the task and side, as well as significant factors related to the extent of AR in the more-affected side.

Previous studies have shown inconsistent results regarding the association between AR and upper extremity function.^{2,5,7-10} Among those studies, only Klingels, et al.⁸ administered MUJL for unimanual function, and found a significant association between MM and the scores of MUJL only in the paretic limb. The results of our study on the association of AR with unimanual function were consistent with those of Klingels, et al.⁸

ARs are present in normal children up to the age of 9 years and then systematically diminish.^{6,17-20} In the present study, vis-

ible AR was more common in younger than in older children. These findings suggest that AR reflects CNS immaturity. However, AR was more common in the more-affected limb than in the less-affected limb, and we discovered a stronger association for visible AR with upper arm function, rather than age, suggesting that both upper arm function and age are related to AR. In addition, visible AR in the less-affected limb was only related to upper arm function. These findings imply that in children with CP, upper arm function plays a more significant role in AR than CNS immaturity in young children.

To our knowledge, the present study is the first to describe muscle activity according to presence of visible AR in children with CP. The present study documented increased muscle activities in the wrist and elbow muscles in the contra-lateral upper limb depending on task and side in children with AR. Also, muscle activation patterns in the non-task limb were different from activation patterns in the task limb. When performing voluntary movements, muscle activity in the contralateral upper arm was increased in both homologous muscles and non-homologous muscles. In patients who had experienced stroke, unintended contralateral upper limb muscle activation across multiple muscles of the contra-lateral non-task upper limb during pinch grip was observed.²¹ In that study, the researchers

Table 4. Comparison of RMS Ratios between Groups with and without AR

	More-affected side		p value	Less-affected side		p value
	AR (+) (n=16)	AR (-) (n=13)		AR (+) (n=10)	AR (-) (n=19)	
Task 1						
Shoulder abductor	6.27±2.97	6.14±2.35	0.457	5.76±1.96	5.52±2.47	0.302
Elbow flexor	6.78±4.77	4.73±1.24	0.034*	6.10±2.53	5.83±2.91	0.271
Elbow extensor	8.98±6.74	5.07±2.09	0.004*	8.26±5.16	5.77±1.88	0.143
Wrist flexor	5.89±1.70	5.23±2.39	0.100	6.95±2.94	5.21±2.03	0.005*
Wrist extensor	6.58±2.49	6.43±1.42	0.390	6.93±3.45	5.69±2.02	0.242
Task 2						
Shoulder abductor	6.15±2.25	5.76±2.60	0.436	5.96±3.81	5.67±1.65	0.330
Elbow flexor	6.01±1.27	5.96±1.26	0.234	6.78±3.17	6.46±3.85	0.268
Elbow extensor	5.82±1.45	8.52±6.38	0.184	7.36±3.44	7.54±4.14	0.451
Wrist flexor	8.16±4.33	6.93±5.29	0.070	7.08±4.52	6.09±2.89	0.469
Wrist extensor	6.15±3.13	5.92±2.35	0.487	6.48±2.34	10.39±7.85	0.112
Task 3						
Shoulder abductor	4.08±1.04	4.63±1.51	0.165	5.36±3.12	4.83±1.85	0.420
Elbow flexor	5.07±1.65	5.10±2.18	0.474	6.40±2.79	8.92±16.41	0.154
Elbow extensor	5.97±2.94	4.55±1.80	0.046*	6.07±2.22	6.12±4.68	0.256
Wrist flexor	6.58±6.02	5.17±2.38	0.341	4.60±2.11	4.74±1.70	0.271
Wrist extensor	7.36±2.98	5.08±1.96	0.025*	5.52±2.06	5.29±2.14	0.491
Total	6.39±1.09	5.68±0.74	0.060	6.37±1.26	6.27±1.55	0.368

AR, associated reaction; RMS, root mean square.

Values are presented as a mean±standard deviation. SEMG data were not available for six children due to poor cooperation throughout the procedures.

*p<0.05 based on Mann-Whitney U-test.

Table 5. Subgroup Analysis according to Age and Bimanual Ability

	Young children (age<9) (n=16)	Older children (age≥9) (n=19)	p value
More-affected side			
AR (+), n (%)	14 (87.5)	6 (31.6)	0.002*
AR (-), n (%)	2 (12.5)	13 (68.4)	
AR total score	6.5 (4.8)	2 (6)	0.003 [†]
Less-affected side			
AR (+), n (%)	7 (43.8)	4 (21.1)	0.273
AR (-), n (%)	9 (56.3)	15 (78.9)	
AR total score	3 (5.3)	0 (3)	0.064
	Good MACS (n=22)	Poor MACS (n=13)	p value
Age (yr)	9.7 (7.5)	8.2 (6.4)	0.539
More-affected side			
MA-2 average	90.8 (29.5)	77.8 (55.5)	0.044 [†]
AR total score	1.5 (6.0)	7.0 (3.5)	0.005 [†]
Less-affected side			
MA-2 average	97.8 (5.9)	87.6 (12.7)	0.003 [†]
AR total score	0 (3)	5 (3)	0.002 [†]

AR, associated reaction; MACS, Manual Ability Classification System; MA-2, Melbourne Assessment 2.

Values are presented as a median (interquartile range) unless otherwise noticed.

*p<0.05 of AR frequency based on Fisher's exact test, [†]p<0.05 of age, MA-2 and AR total score based on Mann-Whitney U-test.

demonstrated that the non-task hand did not mirror the task hand's muscle activation patterns. Since there were differences in the muscles selected for SEMG and unimanual tasks between studies, a comparison of the results of our study with those of previous studies seems to be unreasonable. However, based on those findings, the muscle activity recorded from SEMG seems to differ depending on the side (paretic/non paretic) or upper arm function, type of unimanual task, and muscles selected for recording. In consideration of these factors, further studies are needed.

In the current study, AR was more frequently observed in the more-affected limb. Chiu, et al.¹⁰ also reported that AR is more common in the more-affected limb in people with quadriplegic CP. On the other hand, some studies have reported more frequent MM in the less-affected hand in children with hemiplegic CP.^{5,7,8} Meanwhile, lesion timing is also considered to be a significant factor related to AR in patients with hemiplegic CP. Significantly higher muscle activity in elbow flexion in the paretic hand has been observed in children with hemiparesis in pre- and perinatal brain groups.²² In addition, MM in the paretic hand in hemiplegic CP was related to earlier brain lesions.⁸ Taken together, we propose that there are various factors associated with the occurrence of AR in children with CP, which seem to contribute to the inconsistent results of the studies. Therefore, further investigation of AR is needed in order to characterize AR in consideration of these factors in children with CP.

The lack of a normal control group was a major limitation of

Table 6. Correlation Coefficients with AR Scores and Multiple Regression Analysis for Independent Factors Associated with AR Scores

	Correlation coefficients		Multiple regression analysis			Adjusted R ²
	rho	p value	Beta (SE)	Standardized Beta	p value	
More-affected side						0.510
Age	-0.471	0.004	-0.412 (0.145)	-0.394	0.010	
MA-2	-0.700	<0.001	-0.081 (0.023)	-0.528	0.002	
RMS ratio	0.476	0.012	0.793 (0.561)	0.218	0.171	
Less-affected side						0.183
Age	-0.280	0.103	-0.153 (0.129)	0.129	0.247	
MA-2	-0.414	0.013	-0.105 (0.054)	0.054	0.065	
RMS ratio	0.211	0.291	0.381 (0.309)	0.309	0.230	

AR, associated reaction; MA-2, Melbourne Assessment 2; RMS, root mean square.

Statistics were analyzed by Spearman correlation analysis and entered into multiple regression analysis.

our study. In future studies, the extent of AR in children with bilateral CP should be compared with that of a normal control group. Despite these limitations, this study revealed increased muscle activity in various muscles, as well as factors associated with AR.

In conclusion, in children with visible AR, motor overflow to the elbow and wrist muscles in the non-task hand during uni-manual hand tasks was observed depending on the side and task. Age and upper arm function were significant factors related to the extent of AR in the more-affected limb of children with CP.

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AUTHOR CONTRIBUTIONS

Conceptualization: all authors. **Data curation:** Seung Ki Kim and Eun Sook Park. **Formal analysis:** Seung Ki Kim. **Funding acquisition:** Eun Sook Park. **Investigation:** Han Kyul Park. **Methodology:** Han Kyul Park and Eun Sook Park. **Project administration:** Eun Sook Park. **Resources:** all authors. **Software:** Seung Ki Kim. **Supervision:** Seung Ki Kim and Eun Sook Park. **Validation:** all authors. **Visualization:** all authors. **Writing—original draft preparation:** all authors. **Writing—review & editing:** all authors. **Approval of final manuscript:** all authors.

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