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ORIGINAL REPORT

POSTURAL ALIGNMENT IN CHILDREN WITH BILATERAL SPASTIC CEREBRAL PALSY USING A BIMANUAL INTERFACE FOR POWERED WHEELCHAIR CONTROL

Wen-Yu Liu, PhD[1], Fang-Jie Chen, MS[1], Yang-Hua Lin, PhD[1], Chung-Hsien Kuo, PhD[2], Hen-Yu Lien, PhD[1] and Yu-Jhih Yu, MS[1]

From the [1]Department of Physical Therapy and Graduate Institute of Rehabilitation Science, Chang Gung University, Tao-Yuan and [2]Department of Electrical Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

Objective: **To examine postural alignment in children with bilateral spastic cerebral palsy while driving a powered wheelchair using both a unilateral joystick and an innovative bimanual interface.**
Design: **Cross-sectional study.**
Subjects: **A total of 20 children with bilateral spastic cerebral palsy (mean age 9.0 years (standard deviation 2.1); 11 with diplegia, 9 with quadriplegia) and 14 typically developing children (mean age 7.7 years (standard deviation 2.9)).**
Methods: **All children drove the powered wheelchair in both the unilateral and bimanual conditions. The Seated Postural Control Measure quantified the postural alignment of subjects while driving the powered wheelchair. Statistical analysis was carried out using repeated measures analysis of variance and Spearman's rank correlation coefficient.**
Results: **As expected, typically developing children had better postural alignment in both driving conditions than children with cerebral palsy. Children with cerebral palsy demonstrated more symmetrical postural alignment while using the bimanual interface than when using the unilateral joystick. In addition, the severity of cerebral palsy correlated moderately with postural symmetry in both conditions.**
Conclusion: **The results suggest that this innovative bimanual interface might be beneficial for promoting symmetrical postural alignment in some children with bilateral spastic cerebral palsy.**

Key words: cerebral palsy; wheelchair; posture; powered mobility.

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Correspondence address: Chung-Hsien Kuo, Department of Electrical Engineering, National Taiwan University of Science and Technology, No. 43, Sec. 4, Keelung Rd., Da'an Dist., Taipei City 106, Taiwan (R.O.C.). E-mail: chkuo@mail.ntust.edu.tw

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INTRODUCTION

Cerebral palsy (CP) is the most common physical disability in childhood (1). The condition, caused by non-progressive disturbances occurring during development of the foetal or infant brain, results in a group of permanent disorders of movement and posture that limit activity and participation (2). Approximately 20.2% of children with CP are unable to walk (3) and require a wheelchair to promote early independent mobility and participation in their environment (4). Tefft et al. (5) found that young children, including those with spastic CP, who used a powered wheelchair for 4–6 months, gained the ability to move in their environments as they desired, while also improving social and play skills and interactions within the family. Nevertheless, the effects of operating a powered wheelchair on the body at a functional and structural level have received less attention.

Design variations between commercially available powered wheelchairs result in differences in manoeuvrability (6). An important part of the design of a powered wheelchair is its interface, a joystick conventionally operated with one hand. However, previous studies have shown a relationship between trunk asymmetry and unilateral usage of the upper extremities. Furthermore, previous studies have proposed that asymmetrical loading might cause modifications to the spine (7). Grivas et al. (8) reported that handedness had a significant statistical correlation with trunk asymmetry in a group of children with mild mid-thoracic asymmetry. Moreover, Goldberg et al. (9) matched handedness with same-side scoliotic curve convexity in 82% of children. In addition, Johnson & Yarnell (10) found that asymmetrical forces caused by primary use of a single upper extremity resulted in major scoliotic convexity to the side of patients' handedness in most patients with Duchenne muscular dystrophy. Werner et al. (11) indicated an association between handedness and neuromuscular scoliosis due to factors such as asymmetrical weakness; however, research has not consistently supported this finding. Their study suggested providing patients with anticipatory interventions, such as adjusting the location of the wheelchair interface in order to counterbalance scoliotic curvature and potentially reduce the severity of scoliosis. In summary, findings from previous research have demonstrated that unilateral usage of upper extremities might relate to asymmetry of the trunk, which would lead to the development of scoliosis.

Clinical scoliosis has a prevalence of approximately 39.8% in a population with bilateral spastic CP, with a proportion of up to 16% having a scoliotic curve of more than 20º (12). Loeters et al. (13) reviewed 10 studies and assessed the risk factors associated with the emergence and progression of scoliosis in children with spastic CP. The results of the review showed an association between the severity of motor function, CP subtype, age, hip dislocation, pelvic obliquity, and scoliosis; however, research has not yet examined the correlation between primary usage of upper extremities and scoliosis in children with spastic CP.

Based on the above findings, this study designed an innovative bimanual interface for a powered wheelchair with the intention of promoting symmetrical usage of the upper extremities and postural alignment in subjects with a variety of physical disabilities (14). Subjects were required to manipulate 2 interfaces simultaneously in order to control the wheelchair. Lin et al. (15) demonstrated the differing activation patterns of upper extremities during use of a bimanual interface compared with the use of a conventional joystick and found the bimanual interface was feasible for use by subjects with spinal cord injuries. A preliminary study examining the use of a bimanual interface by 5 children with spastic CP found that its usage might promote better postural alignment for some children with spastic CP (16); however, this did not account for the influence of different wheelchair seat positions on postural alignment in 2 out of 4 children with bilateral spastic CP. Therefore, the aims of this study were: (*i*) to examine postural alignment in children with bilateral spastic CP and typically developing (TD) children while driving a powered wheelchair using either a unilateral joystick or a bimanual interface, and (*ii*) to explore the relationship between the severity of bilateral spastic CP and postural alignment.

METHODS

The Institutional Review Board of Chang Gung Memorial Hospital approved the protocol for this cross-sectional study (98-3983B).

Participants

Children recruited for this study were either patients from Chang Gung Memorial Hospital or acquaintances of the investigators. The inclusion criteria were: (*i*) age 6–12 years, and (*ii*) ability to follow verbal commands. Subjects in the CP group were children with bilateral spastic CP (spastic diplegia or spastic quadriplegia) and rated Levels II–V in the Gross Motor Function Classification System (GMFCS) (17). Children with spastic quadriplegia who also showed superimposed hemiplegia were included in this study provided they were capable of grasping both the unilateral joystick and bimanual interfaces. Exclusionary criteria for the CP group included: uncontrolled epilepsy, uncorrected vision problems, auditory impairments, or inability to spend 30 min in either a wheelchair or an adaptive chair with head and/or side support. For the TD group, exclusionary criteria were any known developmental difficulties or physical, perceptual, cognitive, or psychiatric problems. After children and their parents agreed to participate in the study and signed informed consent, 46 children participated in screening for eligibility. Twenty children with CP and 14 TD children were selected to participate in the study (Fig. 1). Children with bilateral spastic CP were classified using the GMFCS, the Manual Ability Classification System (MACS) (18), and the Functional Mobility Scale (FMS) (19). Demographic data (age, height, weight, and body mass index (BMI)) were recorded, with no significant difference between children with CP and TD children (Table I).

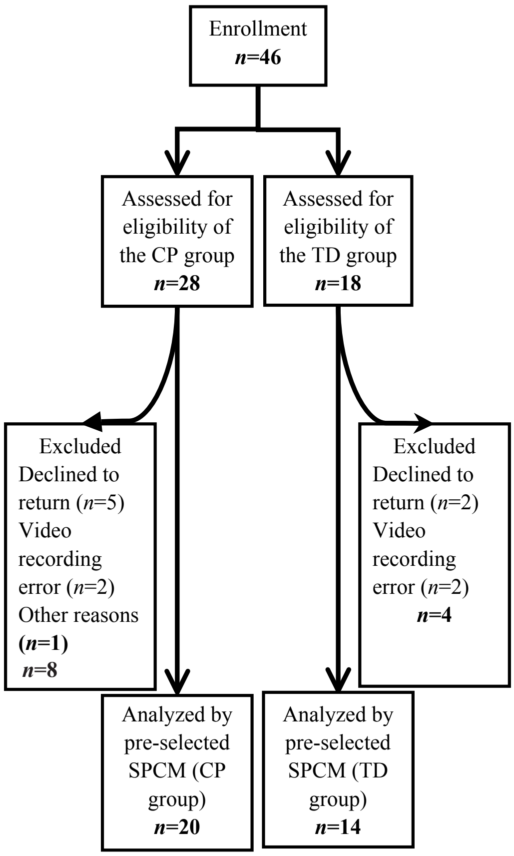

Fig. 1. Subject recruitment and participation of the 2 groups. CP: cerebral palsy; TD: typically developing; SPCM: Seated Posture Control Measure.

Instrument

A commercially available paediatric powered wheelchair (KP-12T, KARMA, Taiwan) was modified to incorporate the bimanual interface and the unilateral joystick. All participants drove the powered wheelchair with both interfaces (the unilateral joystick and the bimanual interface). Subject positioning was standardized, with all children

Table I. *Demographic and selected characteristics by group*

	CP (n=20)	TD (n=14)	p-value
Gender (M/F), n	14/6	5/9	
Dominant hand (R/L), n	14/6	12/2	
Age, years, mean (SD)	9.01 (2.11)	7.66 (2.92)	0.126
Height, cm, mean (SD)	122.36 (11.32)	122.64 (19.15)	0.956
Weight, kg, mean (SD)	25.27 (7.14)	26.37 (12.28)	0.743
BMI, kg/m^2, mean (SD)	16.62 (2.74)	16.6 (2.9)	0.981
GMFCS (II/III/IV)	8/6/6		
MACS (I/II/III/IV/V)	5/5/4/6/0		
FMS5 (C/1/2/3/4/5/6)	6/3/3/0/2/6/0		
FMS50 (C/1/2/3/4/5/6)	0/9/3/0/2/6/0		
FMS500 (C/1/2/3/4/5/6)	0/10/2/0/2/6/0		

CP: cerebral palsy; TD: typically developing; BMI: body mass index; M: male; F: female; GMFCS: Gross Motor Function Classification System; MACS: Manual Ability Classification System; FMS: Functional Mobility Scale, FMS5, FMS50, FMS500 refers to walking ability at 5, 50 and 500 m respectively.

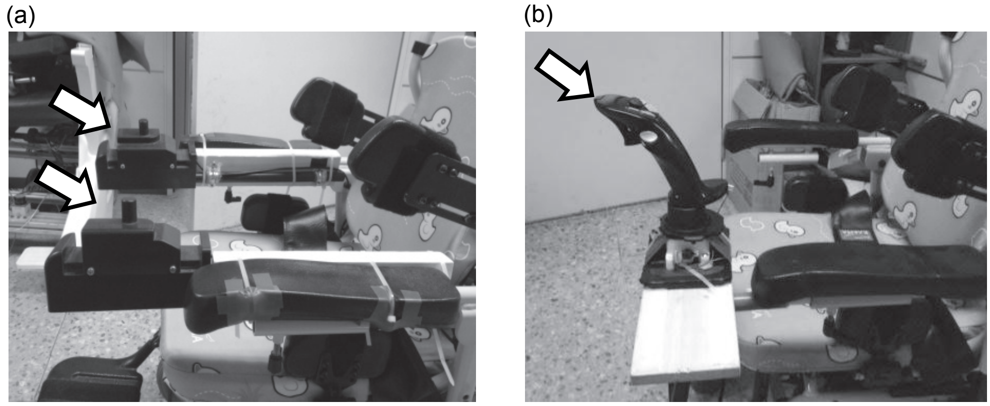

Fig. 2. (a) Bimanual interface and (b) conventional joystick for the powered wheelchair.

driving the powered wheelchair seated with the hip and knee positioned at 90º angles. The bimanual interface comprised one joystick for each gliding interface (Fig. 2a) instead of the original gliding interface (14, 15). The driving method for this interface involved grasping and gliding (pushing) the joystick forward and backward with both hands to control the driving direction. For example, in order to drive straightforward, participants were required to glide both joysticks simultaneously with the same force, while to turn left, they were required to glide the right side joystick forward more forcefully than the left side.

Assessments

A single rater scored each participant as they drove the powered wheelchair, using the postural alignment items from the Seated Posture Control Measure (SPCM) (20, 21). Fife et al. (20) developed the SPCM as a clinical criterion-referenced scale for assessing the specific aspects of postural alignment and functional movement while sitting, in children requiring adaptive seating systems. Recent studies have shown good inter-rater reliability and satisfactory concept validity of the SPCM; however, the responsiveness of the postural alignment items of the SPCM requires further examination (21). The SPCM includes 22 postural alignment items requiring observation of seated postural alignment from anterior, lateral, and superior views. A 4-point, criterion-referenced scale scores observations of each postural alignment item. The scale assigns a normal alignment a score of 4, and mildly, moderately, and severely abnormal alignments of each body segment, marked by 3 increasing angular deviations from normal, are assigned scores of 3, 2, and 1, respectively. Higher raw scores were associated with more typical postures, while lower scores were associated with more deformity.

This study chose all 6 anterior view items and 5 out of the 11 lateral view items to quantify postural alignment. The remaining 6 lateral view items were not included in this study because postural constraint belts for both driving conditions stabilized the lower limbs and the armrest component decreased accuracy for visual observation. Superior view items were not included due to difficulties in making clinical judgments without a camera placed overhead. Thus, a total of 11 items of the SPCM were recorded in this study: pelvic obliquity, trunk lateral shift, shoulder height, head lateral tilt, right and left hip rotation were assessed in the anterior view; and pelvic tilt, lumbar curve, thoracic curve, trunk inclination, and head anterior/posterior tilt were assessed in the lateral view. Anterior and lateral view scores were added separately in order to distinguish between postural changes in the frontal and sagittal planes.

Prior to this study, a sample study of 5 children with CP evaluated the intra-rater reliability of the chosen SPCM items used in this study. Subjects drove the powered wheelchair with the unilateral joystick and the bimanual interface. A single therapist conducted 2 test sessions 40 days apart. The intra-rater reliability test for the 2 driving conditions found moderate reliability (intraclass correlation coeficient $(ICC)_{(3,1)} = 0.74$) for the anterior view scores and good reliability $(ICC_{(3,1)} = 0.76)$ for the lateral view scores.

Procedure

Two cameras were placed in front of and to the left side of the wheelchair circuit of the Pediatric Indoor Wheelchair Maneuverability Test (PIWMT) (22) to record on video the postural alignment and driving performance during both unilateral and bimanual conditions. This test was developed to provide a standardized wheelchair driving test circuit that reflects a child's abilities to control the wheelchair, as well as to examine basic wheelchair manoeuvrability to ensure the child could drive the wheelchair safely in minimally restricted settings according to governmental laws in Taiwan. The test included scores of 10 indoor wheelchair manoeuvrability items and 7 spatio-temporal parameters. All subjects in this study passed the 10 indoor wheelchair manoeuvrability items, which included driving forward, turning, turning around, and rapid stopping, etc. Only 2 spatio-temporal items are reported in this study; driving velocity (calculated as absolute distance divided by driving time) and path length (the actual path driven), as these were the only spatio-temporal items that related to the child's alignment during the SPCM observation period.

Participants were timed while driving a fixed distance (300 cm) at their preferred speed within a rectangular area measuring 160×300 cm. Driving time was measured using a stopwatch (ICC = 1.00 for both inter-rater and intra-rater reliability) (22). Path length was defined as the distance the wheelchair travelled while moving forward 300 cm within the rectangular area. Path length indicated how straight the subjects drove, and was measured using a marking pen attached to the back of the wheelchair as well as an off-line measurement using a trundle wheel (ICC = 0.97 and 0.94 for both inter-rater and intra-rater reliability) (22). All subjects received 2 practice sessions for both the unilateral and bimanual conditions in a random order. Driving was terminated for safety concerns if the child deviated beyond the range of the rectangular area, indicating a risk that the child could deviate far enough to collide with hallway walls, though the width of the hallways fulfilled legal requirements.

Statistical analysis

Statistical analyses were performed using the IBM SPSS Statistics software package, version 19. A 2 × 2 repeated measures analysis of variance examined the total scores from the anterior and lateral views as well as driving performance. The level of significance was set at 0.05. For children with CP, Spearman's rank correlation coefficient examined whether the severity of CP influenced postural alignment and driving performance. A correlation coefficient value of 0.00–0.25 indicated little or no relationship, 0.25–0.50 a fair relationship, 0.50–0.75 a moderate-to-good relationship, and greater than 0.75 a good-to-excellent relationship (23). In addition, *a priori* comparison explored subsequent analyses based on the severity of CP. Children were divided into 2 groups in each classification. Children classified as Levels I and II in the GMFCS were combined into a single group based on their ability to walk independently without assistive devices. Children classified as Level III and IV in the GMFCS were combined into a single group of subjects requiring assistive devices when walking. Children classified as Levels I and II in the MACS were combined into a single group based on their ability to handle most objects. Children classified as Levels III to IV in the MACS were combined into a single group of subjects requiring assistance when managing objects (18).

RESULTS

For all of the children, there were significant differences in postural alignment between the 2 groups ($p=0.03$) and driving conditions ($p=0.03$) in the anterior view. No interaction effect was found ($p=0.28$). In the lateral view for postural alignment, there were significant differences between the 2 groups ($p<0.005$), but not driving conditions. As expected, TD children scored higher than those in the CP group did in both driving conditions from both the anterior and lateral views of the SPCM. All subjects scored higher in total in the bimanual condition than in the unilateral condition on the anterior view. Children with CP gained higher total scores than TD children for the bimanual condition (Table II).

Table II. *SPCM scores and driving performances in unilateral and bimanual conditions*

Items		Unilateral Mean (SD)	Bimanual Mean (SD)		*p*-value
SPCM items					
Anterior view					
Pelvic obliquity	TD	4.0 (0.0)	4.0 (0.0)		
	CP	4.0 (0.0)	4.0 (0.0)		
Trunk lateral	TD	3.9 (0.3)	4.0 (0.0)		
shift	CP	3.5 (0.8)	3.7 (0.6)		
Shoulder height	TD	3.9 (0.3)	3.8 (0.4)		
	CP	3.3 (0.7)	3.5 (0.5)		
Head lateral tilt	TD	4.0 (0.0)	3.9 (0.3)		
	CP	3.2 (0.8)	3.2 (0.9)		
Dominant	TD	3.5 (0.5)	3.6 (0.5)		
hip rotation	CP	3.6 (0.7)	3.8 (0.6)		
Non-dominant	TD	3.1 (1.0)	3.4 (0.5)		
hip rotation	CP	3.5 (0.8)	3.9 (0.4)		
Total score	TD	22.5 (1.0)	22.8 (1.1)	Group	0.03*
	CP	21.1 (2.1)	21.9 (1.7)	Condition	0.03*
				Interaction	0.28
Lateral view					
Pelvic tilt	TD	4.0 (0.0)	4.0 (0.0)		
	CP	4.0 (0.0)	4.0 (0.0)		
Lumbar curve	TD	4.0 (0.0)	3.9 (0.3)		
	CP	3.3 (0.5)	3.4 (0.5)		
Thoracic curve	TD	3.9 (0.3)	4.0 (0.0)		
	CP	3.3 (0.6)	3.4 (0.7)		
Trunk inclination	TD	4.0 (0.0)	4.0 (0.0)		
	CP	2.8 (0.8)	3.0 (0.9)		
Head anterior/	TD	2.2 (0.4)	2.1 (0.5)		
posterior tilt	CP	1.7 (0.7)	1.5 (0.7)		
Total score	TD	18.1 (0.5)	18.0 (0.4)	Group	0.00*
	CP	15.1 (2.0)	15.3 (2.2)	Condition	0.88
				Interaction	0.37
Spatio-temporal items					
Velocity (cm/s)					
	TD	31.1 (7.6)	26.8 (5.2)	Group	0.01*
	CP	22.7 (9.5)	20.1 (10.2)	Condition	0.04*
Path length (cm)				Interaction	0.63
	TD	303.2 (4.2)	309.4 (16.1)	Group	0.18
	CP	311.8 (16.4)	339.2 (88.9)	Condition	0.11
				Interaction	0.31

*Indicates significance.
TD: typically developing; CP: cerebral palsy; SPCM: Seated Postural Control Measure; SD: standard deviation.

Results for driving performance demonstrated that subjects had significantly slower driving velocity using the bimanual interface than the unilateral joystick ($p=0.04$). Children with bilateral spastic CP had significantly slower driving velocity than TD children ($p<0.01$) (Table II).

GMFCS, MACS, and FMS classifications of children with CP had a moderate-to-good relationship with the anterior view items of the SPCM. In the unilateral condition, for GMFCS, $r=-0.64$; for MACS, $r=-0.50$; for FMS_5, $r=0.58$; for FMS_{50}, $r=0.56$; and for FMS_{500}, $r=0.53$. In the bimanual condition, for GMFCS, $r=-0.61$; for MACS, $r=-0.62$; for FMS_5, $r=0.58$; for FMS_{50}, $r=0.60$; and for FMS_{500}, $r=0.60$. In the lateral view, fair-to-moderate and moderate-to-good relationships were found. In the bimanual condition, for GMFCS, $r=-0.53$; for MACS, $r=-0.49$; for FMS_5, $r=0.48$; for FMS_{50}, $r=0.56$; and for FMS_{500}, $r=0.55$. In the unilateral condition, there was only FMS_{50}, with $r=0.45$. In addition, the driving straightness of children with CP in the bimanual condition correlated most strongly with the MACS ($r=0.67$ for the path length) (Table III).

Subsequent analyses revealed significant differences between the 2 groups of CP severity in the anterior view scores

Table III. *Relationships between characteristics and postural alignment in children with cerebral palsy*

		GMFCS	MACS	FMS5	FMS50	FMS500
Anterior view						
Unilateral	*r*	−0.64	−0.50	0.58	0.56	0.53
	p	0.00*	0.02*	0.01*	0.01*	0.02*
Bimanual	*r*	−0.61	−0.62	0.58	0.60	0.60
	p	0.00*	0.00*	0.01*	0.00*	0.01*
Lateral view						
Unilateral	*r*	−0.42	−0.37	0.39	0.45	0.42
	p	0.07	0.10	0.09	0.05*	0.06
Bimanual	*r*	−0.53	−0.49	0.48	0.56	0.55
	p	0.02*	0.03*	0.03*	0.01*	0.01*
Velocity						
Unilateral	*r*	−0.49	−0.56	0.35	0.38	0.38
	p	0.03*	0.01*	0.13	0.10	0.10
Bimanual	*r*	−0.54	−0.64	0.53	0.60	0.51
	p	0.02*	0.01*	0.03*	0.01*	0.04*
Path length						
Unilateral	*r*	0.37	0.52	−0.31	−0.39	−0.45
	p	0.11	0.02*	0.18	0.09	0.04*
Bimanual	*r*	0.52	0.67	−0.49	−0.58	−0.61
	p	0.02*	0.00*	0.03*	0.01*	0.00*

*Indicates significance.
GMFCS: Gross Motor Function Classification System; MACS: Manual Ability Classification System; FMS: Functional Mobility Scale, FMS5, FMS50, FMS500 refer to walking ability at 5, 50 and 500 m, respectively.

Table IV. *Subsequent analyses of severity of postural alignment in children with cerebral palsy for unilateral and bimanual conditions*

SPCM	GMFCS I–II (n=8) Mean (SD)	GMFCS III–IV (n=12) Mean (SD)		p-value
Anterior view				
Unilateral	22.25 (1.91)	20.33 (1.97)	Group	0.03*
Bimanual	22.88 (1.55)	21.25 (1.54)	Condition	0.02*
			Interaction	0.63
Lateral view				
Unilateral	16.13 (1.73)	14.42 (1.93)	Group	0.01*
Bimanual	16.88 (2.03)	14.25 (1.60)	Condition	0.34
			Interaction	0.14
	MACS I–II (n=10) Mean (SD)	MACS III–IV (n=10) Mean (SD)		
Anterior view				
Unilateral	22.20 (1.75)	20.00 (1.94)	Group	0.01*
Bimanual	22.80 (1.40)	21.00 (1.56)	Condition	0.01*
			Interaction	0.50
Lateral view				
Unilateral	15.70 (1.77)	14.50 (2.12)	Group	0.05
Bimanual	16.40 (2.07)	14.20 (1.75)	Condition	0.50
			Interaction	0.10

*Indicates significance.
GMFCS: Gross Motor Function Classification System; MACS: Manual Ability Classification System; SD: standard deviation; SPCM: Seated Postural Control Measure.

of postural alignment (Table IV). Children with more severe CP (GMFCS and MACS Levels III and IV) gained higher scores in bimanual conditions than those with less severe CP (GMFCS and MACS Levels I and II). Lateral view scores showed significant differences for postural alignment between the 2 severity groups classified by GMFCS, but not MACS. No significant differences between the 2 driving conditions were found in the lateral view.

DISCUSSION

This study examined the postural alignment and driving performance of children with bilateral spastic CP, and of TD children when driving a powered wheelchair using either a unilateral joystick or a bimanual interface. All subjects demonstrated slower driving velocity when using the bimanual interface. A previous study comparing able-bodied users and subjects with spinal cord injuries found similar results (15). This may be due to subjects undergoing a process of adapting to the new driving skills required for bilateral arm coordination.

In this study, subjects with CP and diagnosed with either spastic diplegia or spastic quadriplegia were required to operate the bimanual interface using both hands, creating a symmetrical load on the trunk, as opposed to the asymmetrical load caused by using only the dominant hand to operate a unilateral interface. Anterior view scores representing frontal symmetry indicated a more symmetrical postural alignment when using the bimanual interface.

The non-dominant hand is considered to be the less functional, more involved hand in children with spastic diplegic and quadriplegic CP. Forced use of the more involved hand in children with hemiplegia has been shown to decrease postural asymmetry after a 12-day intervention (24); however, similar research has not been conducted on children with bilateral spastic CP. The bimanual interface potentially gave children with spastic diplegia and quadriplegia the opportunity to use their more involved extremities, thus decreasing postural asymmetry. The time-scale for using this device was relatively short in this study; therefore, examining the impact of longitudinal usage of this bimanual interface on postural deformities is a viable option for future research.

Subsequent analyses of severity of CP in affected children found a negative correlation with driving performance and symmetry of postural alignment, as expected. Specifically, children with higher levels of motor function with the ability to handle most objects or walk without the aid of mobility devices were able to drive powered wheelchairs faster and maintain greater trunk symmetry, regardless of the type of interface used. Children with more severe involvement, classified as GMFCS Levels III and IV, and MACS Levels III and IV, in this study, gained higher scores than those with less severe classifications, such as GMFCS Levels I and II and MACS Levels I and II. These results suggested that the children with less severe involvement might have already developed optimal postural control abilities. Therefore, environmental adaptations, such as using a unilateral interface, might not have a negative influence on postural alignment in children with less severe involvement. Conversely, interface design had a greater impact on children with more severe involvement because they were less able to adapt to the asymmetrical task demands.

Cautious interpretation of results is required due to small convenience samples, specific characteristics within the subject population, and the limited opportunity for practice with the interfaces used in this preliminary study. Firstly, a review by Wilson et al. (25) recommended 30 participants per cell for 80% power in order to detect group differences, given a medium-to-large effect size. The lack of a statistically significant difference in the lateral view in the present study may be attributable an insufficient sample size causing a type II error. Secondly, this study recruited only children with spastic diplegia and quadriplegia. Future research is required to explore the impact of the use of the bimanual interface on children with more asymmetrical characteristics. Thirdly, one child had a GMFCS Level V classification, and was able to drive a personal powered wheelchair for daily activities; however, this child was not able to drive the wheelchair provided in this study forwards, but instead rotated on the spot for either interface. Therefore, this subject's postural alignment was not quantified. This indicated that the child might have required more practice with the controls of the interfaces. The benefits of powered wheelchair/mobility training have been reported in several studies (5, 26, 27). Further practice with interface controls should therefore be provided in order to explore the possible benefits of this innovative bimanual interface. Finally, this study used off-line video analysis without manual palpation in order to ensure the reliability of SPCM scores and to minimize the risk of video apparatus interfering with the child's driving ability. Therefore, it was highly likely that this study reported only large and obvious discrepancies seen from visual inspection.

The wheelchair and seating components obscured the pelvis in neutral tilt at the beginning of each trial, as shown by the full score of the "Pelvic obliquity" and "Pelvic tilt" items. However, it was found that children with CP tended to change their alignment immediately when they started to drive. Lower scores at the lumbar and thoracic levels (presumably due to kyphotic posture) reflected this observation. Cautious interpretation of this study was therefore required due to uncertainty of milder obliquities and posterior pelvic tilt, especially from the lateral view. Future research exploring concurrent validity between the SPCM and hands-on examination is required to determine the clinical applications of using the SPCM to detect the minor postural deviation.

In conclusion, the results of this study suggest that the use of bimanual interfaces might promote greater symmetrical postural alignment in children with bilateral spastic CP than a unilateral joystick, especially for those with more severe CP. Further investigation is warranted to examine the impact on other types of CP; the effects of different interface positions, including comparisons with midline positioning for the unilateral joystick; and the prevention of asymmetrical postural alignment as well as the potential improvement of driving speed in response to longitudinal usage of a bimanual interface.

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