Application of A Novel Integrated Pointing Device Apparatus for Children with Cerebral Palsy

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Background: To improve the computer operation of children suffering from cerebral palsy (CP) with severe disabilities, more flexible pointing devices are required. This study investigates the effectiveness of a newly developed Integrated Pointing Device Apparatus (IPDA) that can integrate numerous commercial pointing devices.

Methods: We enrolled 27 children with quadriplegic CP and 15 healthy children. All children were required to perform three specific mouse operation tasks. Children with CP were classified into two groups based on hand operation: one hand (group A) and both hands (group B). The efficiency of children with CP in each mouse operation task was expressed as a percentage of that for normal children (% NL).

Results: Group A operated a standard mouse with their dominant hand; group B had to use both hands to operate a mouse via IPDA. Group A demonstrated better efficiency of continuous-clicking tasks than group B ($p < 0.05$). Group B had a similar level of efficiency in the target-acquisition task (30% NL) and drag-and-drop task (20% NL) as that of group A, although group B could not operate a standard mouse with one hand. All children in group A were spastic quadriplegia, while 30% of children in group B were spastic-athetoid ($p < 0.05$). All children in group B were at level 3 of the gross motor functional classification system (GMFCS) but only 57% of children in group A were at level 3 ($p < 0.05$).

Conclusion: The IPDA can help some children with CP, who cannot utilize a commercial mouse alone, to achieve acceptable operational efficiency. The operation methods for children with CP were determined by their underlying motor control.

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Key words: computer mouse, pointing devices, cerebral palsy, efficiency.

Children with severe physical disabilities often require special devices to aid in performing everyday tasks such as mobility, communication, environmental control and computer operation.[(1)]

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Cerebral palsy (CP) is a common cause of disability in children. Most children with CP who have upper limb disabilities encounter difficulties during certain learning activities, especially writing-based activities. Recent developments in computer operating systems and the use of graphical user interfaces (GUIs) have made pointing devices rather than keyboards primary input devices for children with CP. Healthy children can use a standard mouse, while children with moderate to severe CP have difficulties. It is important, therefore, that efficient computer input devices are available to children with CP who have such physical disabilities.

In meeting the individual needs of children with different physical disabilities, standard human-computer interfaces, such as the keyboard and mouse, are modified or alternative electronic techniques applied in the development of special devices.(2) Such special human-computer devices comprise head-controlled interfaces built with optical or ultrasonic controls,(3-6) eye-controlled interfaces employing optical controls,(7,8) force-controlled interfaces activated by pressure sensors(9,10) or foot-controlled interfaces that are position-controlled.(11) However, these special devices are typically expensive and custom-made to suit individual needs. Until recently, there was no universal pointing device that met the individual needs of children with CP who are unable to use commercial pointing devices.

Numerous studies have investigated the use of different special devices that aid children with CP to operate computers.(12,13) Some studies identified differences in the effects of interface design between novice and experienced users, and noted that some special interface designs may reduce operational performance.(12) Other studies determined that particular special interfaces could enhance user performance using a head-controlled computer input device.(13) These conflicting findings may be a result of varying degrees of disability and evaluation methodologies. Therefore, the development of assessment software for testing operational performance is necessary to objectively determine the suitability of human-computer interfaces for people with different physical disabilities.(14,15)

To improve the computer operation of children with CP who have severe disabilities, more universal and economical pointing devices are required. However, the development of such devices is challenged by the wide range of physical disabilities CP produces, and the cost and maintainability of special pointing devices. To accommodate a large variety of physical disabilities in children with CP, the apparatus must allow for several alternative pointing device combinations. This study presents a novel flexible apparatus, Integrated Pointing Device Apparatus (IPDA), that can be configured in various combinations to suit individual needs by integrating different currently available commercial pointing devices. This study evaluates the use of this novel apparatus by children with CP who are otherwise unable to operate standard pointing devices.

METHODS

Subjects

Twenty-seven children with CP (15 boys and 12 girls), aged from 5 to 12 years, from the rehabilitation department at our hospital were enrolled in the study. The inclusion criteria were as follows: (1) severe spastic CP with quadriplegia or athetoid CP with quadriplegia; (2) able to manipulate the devices used in this study; (3) good cooperation during examination; (4) able to understand the commands; (5) good vision after visual correction and, (6) no active infection such as pneumonia. A group of 15 age-matched healthy children (10 boys and 5 girls), aged from 5 to 11 years, with no known history of brain lesions, visual or hearing impairment, or orthopedic or neuromuscular disorders were selected as the control group for comparison of the mouse operation tasks. This study was approved by the institutional review board at our hospital.

Experimental setup

Subjects sat in an upright position, their elbows resting on the table and flexed to 90 degrees, and with their eyes at a distance of 80 cm from the computer screen. The screen size was 14 inches with 0.35 mm/pixel resolution with screen resolution set at 1024 x 768. The experiment assessed three key pointing device operational performances: continuous-clicking, target-acquisition and target drag-and-drop tasks. Each task was repeated three times. A 3-min rest period between each task and 1-min rest period between each repetition were enforced. Subjects were allowed practice trials to familiarize themselves with the experimental setup.

Instrumentation

The IPDA, built with a circuit board and a microprocessor, provides two PS/2 input connectors for commercial pointing devices (Fig. 1).[19] Each pointing device can be reconfigured by setting a 10-digit dip switch. The control codes from two connected pointing devices were converted and integrated into the control code of a single pointing device by the microprocessor according to their respective switch settings. The integrated control code was then connected to a personal computer via a USB interface. The IPDA also has a pair of external switches that serve as the left and right buttons on a conventional computer mouse. The IPDA conforms to standard USB interface specifications and has been confirmed to be compatible with all Logitech mice and trackballs, and a variety of commercial mice with PS/2 connectors.

The design goal of the IPDA is to develop an economical apparatus that can flexibly integrate commercial computer mice and trackballs, thereby tailoring to individual needs, enhancing individual performance, reducing cost and improving the maintainability of special equipment. Subjects were allowed to operate pointing devices/switches with one body part or any two body parts, such as hands, wrists, chin etc., to facilitate better controllability. For instance, with IPDA, children with CP could operate a computer using both hands with one hand controlling a trackball and the other hand controlling an external switch (Fig. 2). The design of the IPDA allows users to select the most suitable combination of pointing devices and thereby improve the operational performance of children with different disabilities.

Fig. 2 A child with cerebral palsy operates a mouse via an Integrated Pointing Device Apparatus. The child uses the mouse for cursor control with his dominant hand and uses an external switch for click control with the other hand simultaneously.

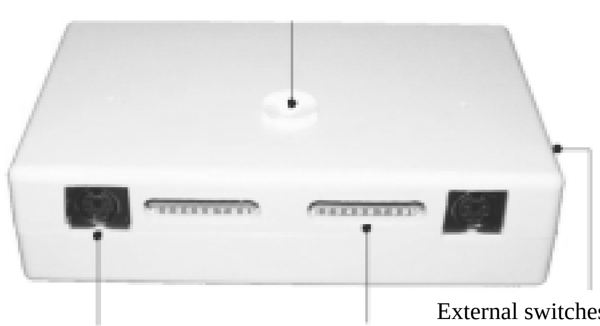

Fig. 1 Integrated pointing device apparatus hardware.

The assessment software was programmed in Visual Basic and run on an IBM portable computer (IBM Think Pad, Ultra base 570E). The software was developed to assess a basic level of mouse operation: continuous-clicking, target-acquisition and drag-and-drop tasks. A test was defined as a failure if the total time taken to complete a single target-acquisition or drag-and-drop task exceeded five minutes. Task timing started when the cursor moved away from its home position and stopped when all targets were successfully acquired in the target-acquisition tests or were dragged and dropped into a central box in the drag-and-drop tests.

(1) Continuous-clicking

Subjects were asked to click as fast as possible for 10 seconds in a large square box displayed on the screen. The box area covered half of the screen to avoid the cursor exceeding the test area. The total number of clicks was recorded as an index of efficiency.

(2) Target-acquisition

The target-acquisition task took into account moving distances, target sizes and moving directions.[20] Each target-acquisition task trial was designed by randomizing a sequence that combined different moving directions, distances and target sizes. There were a total of 16 different combinations comprising eight directions, two distances (150 and 300 pixels) and two rounded target sizes (30 and 90 pixels in diameter). In each trial, the participant was asked to move the cursor to the target and click on it as rapidly as possible. The next target appeared once the target was captured. A target-acquisition trial was not completed until all 16 targets were successfully captured or the total time exceeded five minutes. A total of three different trials were tested to reduce practice effects. The completion time of each trial was recorded for further analysis.

(3) Drag-and-drop

In the drag-and-drop task, subjects were asked to individually select 12 objects surrounding a box and drag each object into the box. The 12 targets were evenly distributed on a circle with the box located at its center. The distance from the surrounding objects to the central box was seven times the size of the targets. The subjects were required to randomly choose a target and drag-and-drop it into the central box until all 12 objects were removed or the total time exceeded five minutes. The completion time was recorded for further analysis.

Assessment procedures

Information was collected by combining demographic data and clinical assessment to identify difficulties in controlling a mouse for each subject with CP. The IPDA, a standard computer mouse and a mechanical switch were utilized in this study. As mentioned, the IPDA allowed for different combinations of pointing devices by integrating commercial pointing devices such as trackballs, standard mice and mechanical switches. Therefore, the subjects could operate the mouse with one hand only or with both hands via the integration of the IPDA. The evaluation course for a subject was restricted to one hour due to subject limited physical strength. Some subjects with CP could use one hand to operate the standard mouse and accomplish all tests. However, other subjects could not accomplish the target-acquisition or drag-and-drop tasks using only one hand. These subjects needed to use both hands simultaneously to operate a mouse and an external switch to accomplish all tests. That is, they used a mouse for cursor control with the dominant hand and used an external switch for click control with the other hand simultaneously. Finally, the subjects were classified into two groups based on the hand operation: one hand (group A) and both hands (group B).

Each child underwent a pointing device operation efficiency evaluation, based on software developed for this study. Children with CP also received clinical assessment of their motor skill deficits. Clinical assessments included CP type (spastic quadriplegia or spastic-athetoid), severity, muscle strength, muscle tone and upper limb control of bilateral upper limbs. Severity was measured using the 5-point gross motor functional classification scale (GMFCS).[16] A modified Ashworth scale with a 6-point rating scale[17] was applied to assess muscle tone. A 6-point manual muscle test scale[18] was utilized to assess the muscle strength of bilateral upper limbs, including shoulder flexor, elbow flexor, wrist flexor and finger flexor. The upper limb control consisted of proximal and distal control. The proximal control involved a shoulder/elbow elevation test, which comprised eight tasks: hand to shoulder, hand to mouth, hand to nose, hand to ear, hand to occipital, hand to neck, hand to scapula (total score: eight). The distal control consisted of four tasks of finger opposition movements: thumb to index finger, thumb to middle finger, thumb to ring finger, thumb to little finger (total score: four).

Data analysis

The subjects' operational efficiency for the three tasks was derived from the recorded data. The continuous-clicking efficiency was defined as the total number of clicks within 10 seconds. The target-acquisition and drag-and-drop efficiencies were defined as the number of targets acquired[16] and the number of targets dropped,[12] respectively, divided by the total test time. For each task, the average efficiency of healthy children was taken as 100% and the efficiency of children with CP in each corresponding task was expressed as a percentage of a healthy performance (% NL) in each corresponding task.

The functions of dominant upper limbs, which control cursor movements, were selected for data analysis. Upper limb control was expressed as a percentage of the subtest score divided by the corresponding subtest total score. Differences between CP groups, including demographic data (age, height and weight) and upper limb control were tested using an independent t-test. Effects of gender, dominant limb and CP type on demographic distribution were determined using a Chi-square test or Fisher's exact test. The Mann-Whitney test was applied to test the differences of clinical assessment (GMFCS), muscle strength and muscle tone between CP groups. A repeated measures ANOVA was used to test operational efficiencies of the three tasks (continuous-clicking, target-acquisition and drag-and-drop tasks) between CP groups. The task was the within factor and the CP group was the between factor. A value of $p < 0.05$ was considered statistically significant.

RESULTS

Fourteen children with CP could use a standard mouse with one hand (group A). Thirteen children with CP used both hands to operate a mouse and an external switch simultaneously (group B). That is, group A had the ability to operate a standard mouse without using IPDA but group B had to rely on IPDA to operate a standard mouse. No significant differences in the demographic data were found between the two groups of children with CP (Table 1).

Clinical assessment of CP

Table 1 summarizes the clinical assessments of the two CP groups. All children in group A were spastic quadriplegia, while 30% of children in group B were spastic-athetoid ($p < 0.05$). All children in group B were level 3 in the GMFCS but only 57% of children in group A were level 3 ($p < 0.05$). Group A performed better shoulder/elbow elevation than group B ($p < 0.05$). The muscle tone of the elbow flexor, wrist flexor and finger flexor of the dominant hand in group A children was greater than that of group B children ($p < 0.05$). However, the muscle strength of the dominant upper limbs, finger opposition subtests and the muscle tone of the shoulder flexor did not achieve significant differences between the two groups.

Pointing device operational efficiency

All CP groups demonstrated worse operational efficiency in all tasks when compared to the healthy subjects (Table 2). Group A (54% NL) showed better efficiency in performing continuous-clicking tasks than group B (40% NL) ($p < 0.05$). However, group B had similar operational efficiency in the target-acquisition (approximate 30% NL) and drag-and-drop tasks (approximate 20% NL) as group A.

Table 1. Demographic and Clinical Data of Children with Cerebral Palsy (CP)

	Group A (n = 14)	Group B (n = 13)	p
Demographic data			
Age	7.3 ±2.1	8.9 ±2.2	0.057
Height (cm)	113.1 ±8.7	119.2 ±10.6	0.113
Weight (kg)	22.9 ±5.6	21.1 ±3.2	0.344
Gender (male)	10 (71.4%)	5 (38.5%)	0.091
Dominant hand (right)	8 (57.1%)	10 (76.9%)	0.249
Clinical data			
CP types			0.041†
Spastic	14 (100.0%)	9 (69.2%)	
Spastic-athetoid	0 (0.0%)	4 (30.8%)	
GMFCS			0.009*
Level 2	6 (42.9%)	0 (0.0%)	
Level 3	8 (57.1%)	13 (100.0%)	
Upper limb function			
Proximal: Shoulder/elbow			
Upward rotation (%)	89.3 ±4.5	85.6 ±4.7	0.047†
Distal: hand			
Finger opposition (%)	78.6 ±27.5	75.0 ±39.5	0.786
Muscle strength			
Shoulder flexor	3.43 ±0.76	3.85 ±0.38	0.102
Elbow flexor	3.21 ±0.80	3.62 ±0.51	0.186
Wrist flexor	3.29 ±0.61	3.31 ±0.75	0.830
Finger flexor	3.36 ±0.50	3.23 ±0.83	0.830
Muscle tone			
Shoulder flexor	0.43 ±0.85	0.69 ±1.03	0.398
Elbow flexor	1.89 ±0.45	1.35 ±0.83	0.029†
Wrist flexor	1.86 ±0.36	1.46 ±0.48	0.019†
Finger flexor	1.61 ±0.59	0.69 ±0.85	0.009*

Abbreviations: GMFCS: gross motor functional classification scale.
Differences in the continuous data were compared using the independent t-test. Differences in non-parametric data were determined by the Chi-square test or Mann-Whitney test.
* $p < 0.01$
† $p < 0.05$

DISCUSSION

The proposed IPDA is inexpensive, easily implemented and compatible with numerous commercial pointing devices. The production cost of an

Table 2. Mouse Operation Efficiency of Children with Cerebral Palsy (CP)

Task speeds	Group A (n = 14)	Group B (n = 13)	*p* Within factor (tasks)	*p* Between factor (groups)
Continuous-click			< 0.001	0.025*
Counts/sec	2.02 ±0.58	1.51 ±0.50		
(% NL)	(54.5 ±15.6)	(40.8 ±13.4)		
Target-acquisition				0.592
Counts/sec	0.24 ±0.10	0.20 ±0.20		
(% NL)	(31.7 ±12.9)	(27.4 ±26.6)		
Drag-drop				0.866
Counts/sec	0.06 ±0.04	0.07 ±0.05		
(% NL)	(21.0 ±11.9)	(22.0 ±17.7)		

* $p < 0.05$

For comparison with normal children, mouse operation performance efficiency of three tasks in CP children was also expressed as the percentage of normal (% NL) in the corresponding test. Differences in the task speeds between the two groups were compared using a repeated measures ANOVA.

IPDA is less than 30 USD even under small-scale production of 100 pieces. This apparatus allows for flexible adjustments and a combination of two commercially available computer-pointing devices to fit a user's control functions for two body parts. The flexibility of IPDA allowed this device to meet the needs of most children with CP who are unable to operate common computer mice and trackballs alone.

This apparatus not only enables these children to operate a computer via commercial pointing devices but also improves their operational efficiency and posture as they operate the pointing devices with their better functioning body parts. Cook and his colleagues argued that mouse usage may contribute to musculoskeletal injury of the neck and upper extremities.[21] It certainly may cause secondary damage to users with CP if ergonomically unsound workstations or pointing devices are utilized, or if they overuse and operate a mouse while sitting in awkward postures.[21-22] Some specialized devices, including head-mounted controllers, may increase the risks of cervical lesions from repetitive impact on the cervical spine in some athetoid CP users who have the potential of cervical degenerative changes or even myelopathy due to severe involuntary movement of the neck.

Results from this study demonstrate that mouse operation methods are associated with CP types, GMFCS, proximal upper limb control and muscle tone but not with muscle strength. These findings indicate that CP type combined with underlying motor control, not muscle strength alone, may be the dominant factors in determining mouse operation methods. Therefore, most children with spastic quadriplegia or with better motor control could use one hand to control a standard mouse. Most computer users with spastic-athetoid or with worse motor control have to use IPDA combinations for cursor and click control with both hands simultaneously. Therefore, spastic quadriplegic CP users with good motor control can operate a standard mouse and spastic quadriplegic CP users with poor motor control or spastic-athetoid CP users can operate common pointing devices in combination with IPDA.

The IPDA could allow some children with CP and severe physical disabilities to operate the cursor movement with acceptable efficiency in basic mouse-operated functions, who could not otherwise control a standard mouse. In this study, group B, who used the IPDA, had similar operational efficiency in target-acquisition (30% NL) and drag-and-drop tasks (20% NL) as group A, who had the ability to use a standard mouse, even though group B children were unable to complete the target-acquisition and drag-and-drop tasks with a standard mouse alone. Trewin and Pain[23] noted that computer users with motor disabilities had difficulties with all aspects of mouse operation, particularly when dragging an object. Radwin et al.[24] determined that the average movement time when using a lightweight ultrasonic head-controlled pointing device was 63% longer than that for a standard mouse moved by healthy subjects. These findings suggest that IPDA could provide better efficiency as a standard pointing device for some children with CP who cannot control a standard mouse.

The novel IPDA design presented in this study demonstrates the following advantages: flexibility, low cost and acceptable efficiency. The IPDA accommodates flexible combinations of devices by integrating two common computer-pointing devices controlled by two different body parts. The IPDA could enable some children with CP and severe physical disability, who could not control a commercial mouse, to achieve acceptable efficiency in basic mouse operational functions. The choice of mouse operation methods for children with CP could be based on CP type and underlying motor control capability. A clinician could therefore select a suitable combination of common pointing devices for a child with CP based on a clinical assessment. Moreover, to achieve optimal operative performance, ergonomic factors such as operating posture, force exertion level, workstation design and work duration should also be considered.

Based on our experiences, the IPDA used in this study not only can be used by children with CP but also by people with severe upper limb disabilities caused by spinal cord injury, traumatic brain injury or amputation etc. People with severe disabilities can thus utilize this apparatus to integrate a variety of commercially available pointing devices and improve their control during computer operation.

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新型電腦指標輸入整合器於腦性麻痺兒童之應用

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背 景：為了促進嚴重肢體功能障礙之腦性麻痺兒童之電腦操作，需要較具彈性之電腦指標輸入器。本篇研究探討可整合許多商業用電腦輸入器之新研發電腦指標輸入整合器 (IPDA) 應用於腦性麻痺兒童之效果。

方 法：收集 27 位四肢麻痺之腦性麻痺兒童及 15 位健康兒童，所有兒童皆接受三種特定之滑鼠操作作業。根據腦性麻痺兒童操作手之使用方式分成二組：單手操作 (A 組) 及雙手操作 (B 組)。每種滑鼠操作作業，腦性麻痺兒童之績效以正常兒童之百分比 (% NL) 表示。

結 果：A 組兒童可以慣用手操作一般滑鼠，而 B 組則需透過 IPDA 才可以雙手操作滑鼠。A 組在連續按鍵作業上之績效較 B 組為佳 ($p < 0.05$)。雖然 B 組無法單手操作一般滑鼠，但是在移動點選作業 (30% NL) 及拖曳施放作業 (20% NL) 績效和 A 組類似。A 組之兒童全為痙攣型四肢麻痺，而 B 組有 30% 個案為痙攣徐動型 ($p < 0.05$)。在粗動作功能性分類上，B 組兒童皆為第三級，但 A 組只有 57% 為第三級 ($p < 0.05$)。

結 論：IPDA 可協助無法單獨使用商業用滑鼠部份腦性麻痺兒童達到可接受之滑鼠操作績效，腦性麻痺兒童滑鼠操作方法主要由其潛在運動控制決定。

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關鍵字：電腦滑鼠，電腦指標輸入器，腦性麻痺，績效。

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