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Case Study

Assistive drawing device design for Cerebral Palsy children

Fong-Gong Wu*, Eva Chang, Rain Chen and Chien-Hsu Chen
Department of Industrial Design, National Cheng Kung University, 1, Ta-Hsueh Road, Tainan, Taiwan 70101, ROC
Tel.: +886 6 2826451; Fax: +886 6 2826452; E-mail: fonggong@mail.ncku.edu.tw

Abstract. Assistive drawing devices help Cerebral Palsy children to communicate and express themselves. This case study introduces the design of a unique assistive drawing device for a Cerebral Palsy child with upper limbs disability using the USERfit framework for user-centred design. The product design includes three parts: (1) hand-grip assistive device, (2) arm support assistive device and (3) moving drawing board. To further clarify the feasibility of applying this assistive drawing device design, a comparison experiment is performed for another Cerebral Palsy child. This study concludes that: (1) Hand grip, arm movements and body posture must be considered when designing assistive drawing devices for Cerebral Palsy children with upper extremity disabilities to improve drawing movement. (2) In terms of drawing agility, stroke, hand (or body) posture and stability, the assistive drawing device presented here can improve drawing range and drawing movement and is superior to currently used assistive drawing devices.

Keywords: Assistive devices, drawing aid, cerebral palsy, USERfit

1. Introduction

Cerebral Palsy is a common and highly handicapping pediatric condition, occurring at a rate of around 1.4 to 2.4 per 1000 live births [8]. Classifying Cerebral Palsy is difficult because the condition has neither a single cause, nor a characteristic course. Motor deficit frequently is the most obvious disability. Consequently related dysfunctions include cognitive deficits, communication disorders, visual dysfunction, seizures, emotional and behavior disorders, sensory impairments and orthopaedic deformities [11]. Many assistive devices have been designed to help Cerebral Palsy children, and several studies have examined the effectiveness of computer assistive devices training based on case study records [3,4,6].

Assistive communication devices provide Cerebral Palsy children receiving special education with significant physical and psychological improvement by enhancing their social and life skills. Many Cerebral Palsy children who are unable to communicate through speech or gestures can still communicate by writing. Moreover, children with communication problems usually also have cognitive dysfunction and must use pens and paper to assist their communication [9]. Levine's work demonstrated that some children with learning disabilities suffer no fine motor problems in other fields, except for writing with a hand-held pen. Poor sensation in proprio-motion feedback makes these patients too visually dependent, or causes them to hold pens very tightly, when writing, to obtain feeling between their finger joints [5]. There are different types of assistive communication devices. Thickened pens and specially designed pens are just one variety.

Studies demonstrate that the evaluation of general assistive technology should begin with understanding users, assessing their cognition, sensation and speech abilities, then selecting assistive devices and providing relevant training [2]. Regarding current assistive device

*Corresponding author.

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Table 1
Subject hand-related measurements

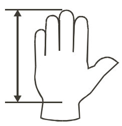
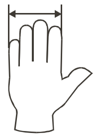
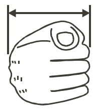
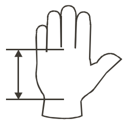
			
Hand length	Hand width	First joint length of the middle figer	Palm length
122mm	53mm	39mm	73mm

Table 2
The present drawing operation ability of the original subject

	Items	Performance index
1.	Stroke	Unable to draw a straight line, only able to draw dots
2.	Distance	Restricted drawing range due to arm stiffness
3.	Hand posture	Display of ulnar deviation, palmar flexion, wrist elevation
4.	Stability	Raised wrist, trembling hand during drawing

design procedures, it has been suggested that allowing users to participate directly in the design process enables designers to understand the real needs of the user and increase product usability [1].

Increasing numbers of Cerebral Palsy children have been encouraged to draw, which affords them a method of communication and an opportunity for self-expression. This work designs a user-friendly assistive drawing device using the USERfit framework to help Cerebral Palsy children with upper limbs disability overcome the limitations their physical disabilities place on their painting while simultaneously helping them to relieve tension, express creativity and generally improve their quality of life.

2. Subject area

This study involved the design of assistive drawing devices for a Cerebral Palsy child. The case study method was employed because of the complex multiple-handicapping condition of the Cerebral Palsy condition and the large differences in symptoms among individual patients.

2.1. Subject

The subject was a ten year old female, currently studying in the St. Ralphael Opportunity Centre in Tainan. She suffers from Cerebral Palsy, having mixed type motor disability, with severe symptoms including general weakness, inability to walk, speech defect, insufficient strength to grip pens and inability to write. Furthermore, her figure appeared thinner and smaller than normal children because of developmental impairments. However, intellectual capacity is normal.

2.2. Anthropometrical measurement of the hand

Table 1 lists the various lengths of the subject's hand as measured with a vernier calliper. Such anthropometrical measurements must be considered when designing assistive devices.

2.3. Painting tools

Regarding hard pens, the subject had improved from requiring thickened pencils to using standard pencils. Regarding soft pens, a T-shaped cloth band sewn by the Opportunity Centre and a T-shaped stick bought from a hardware store are currently used together to stabilize the pen and hand and help the subject to paint.

2.4. Behaviour observation

Regarding hand tools and hand-operated equipment design, it is essential to keep wrists straight and avoid ulnar and radial deviation, palmar flexion and dorsiflexion. Experiments demonstrate that grip strength decreases with bending of the wrists [10]. Pen grip method thus significantly influences writing performance for the Cerebral Palsy subject. The subject was observed to hold the hard pen with the index finger overlapping the middle finger. Meanwhile, the subject also gripped a soft pen with a T- shaped stick between the index and middle fingers and a T-shaped cloth band for assisting the hand in holding the pen while drawing. The gripping technique used by the subject to operate soft and hard pens is as follows (Fig. 1):

(1) Using the index and the middle fingers to hold the pencil.

Table 3
Sequential analysis table presenting case study objectives of the nine elements of the "USERfit" framework

USERfit elements	Case study objectives
Environmental context	Consider a Cerebral palsy child who likes to draw as a case study and help that child to express him or herself creatively
Product environment	Assist a drawing device that can be easily installed and maintained
User analysis	Consider the people involved in developing the product: a girl with severe symptoms of cerebral palsy
User activities	Design a product for a girl who suffers from general weakness, arm stiffness, inability to grip, and difficulty in holding a pen
Product analysis	Consider functional aspects of the product that include increasing hand activity range, avoiding ulnar deviation and palmar flexion
Product attribute matrix	Facilitate the hand in moving agilely and supporting the arm effectively
Requirement summary	Avoiding ulnar deviation and palmar flexion while holding a pen, supporting and assisting the arm, and increasing drawing range by moving the drawing paper
Design summary	Consider the functional specification for the product, which includes three parts: 1. Hand- grip assistive device with a hard U-shaped wrist pad inside the glove and a handle bar 2. Arm support assistive device 3. Moving drawing board with a handle knob
Usability evaluation	Assess the drawing pen, drawing range and drawing posture accuracy

(2) Right palm unable to grip while drawing.
(3) Wrist suspended in the air, supported by the pen and elbow.
(4) Hand exhibiting ulnar deviation and palmar flexion.
(5) Drawing with small pushing movements.
(6) Occasionally raising the upper arm to draw in an attempt to increase drawing range, but thereby simultaneously increasing the burden owing to shoulder elevation.

2.5. Expert suggestions

Regarding current drawing devices and conditions, Shih-Chuan Huang, a teacher who has dedicated over ten years to special education work made the following observations:

(1) Soft and hard pens are not significantly different to Cerebral Palsy children.
(2) Difficulty in raising the arms limits such patients to drawing on flat surfaces.
(3) Such patients should not draw for more than 45 minutes during each drawing session.
(4) Hand activity and rehabilitation may be enhanced by drawing.
(5) Drawing range can be increased through education.

2.6. Performance index

Through observation, the present drawing ability of the subject is described using the performance index, which is displayed in Table 2, which includes stroke, distance, hand posture and stability.

3. Design development

The design procedure used in this study is based on "USERfit" [7], and Table 3 lists the nine design analysis elements and the objectives of this case study in the USERfit framework.

From the above analyses, Fig. 2 illustrates final product design, which incorporates three parts: (1) hand-grip assistive device, (2) arm support assistive device and (3) moving drawing board.

3.1. Hand-grip assistive device

The "T-shaped band" and "T-shaped stick" which the subject used to stabilize pens and the hand were too rough and imprecise. For ease of use and to avoid ulnar deviation and palmar flexion, the hand-grip assistive device presented here includes a glove containing a hard U-shaped wrist pad to avoid ulnar deviation while drawing, as well as a handle bar. Sticking plaster may be used to facilitate grip tightness.

3.2. Arm support assistive device

The universal arm support assistive device, which can be adjusted horizontally and vertically to match user needs and table height, was designed to help the subject to overcome her arm weakness and disability. The functions of the arm support assistive device include: (1) increasing arm activity, (2) increasing arm stability, and (3) increasing drawing range.

Fig. 1. Current conditions of the original subject's use of pen tools.

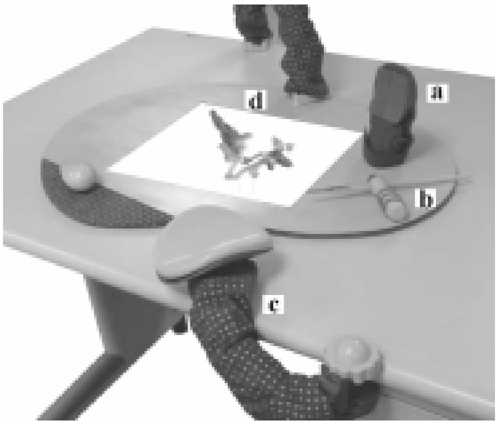


Fig. 2. Final product design. a: Glove of the hand-grip assistive device. b: Handle bar of the hand-grip assistive device. c: Arm support assistive device. d: Moving drawing board.

3.3. Moving drawing board

To increase the product's integrity, a moving drawing board with a handle knob was designed that incorporates hand-grip and arm-support assistive devices for assisting the left hand in moving the paper while drawing. Rolling beads were inserted beneath the drawing board, allowing it to be easily positioned as desired using the handle knob. Notably, this drawing board can be used according to location and user ability. The moving drawing board is designed to help the user to move the paper while drawing, encourage left hand movement, and increase the drawing range.

3.4. Assessment and revision

Following product design, the subject was invited to test the product, and the teacher made the following observations:

(1) The space around the thumb curve is too small, and thus the opening should be increased.
(2) The glove space for the four fingers is too long, and should be shortened.
(3) Owing to the extreme rigidity in the left arm and the weak hand, it is difficult for the subject to control the position of the moving drawing board.

4. Evaluation

Evaluation of this case study was based on measurements conducted during experiments, as well as subjective and expert ratings. Measurements included agility, stroke, hand posture, stability, and so on.

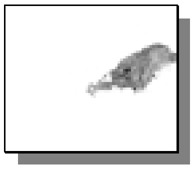
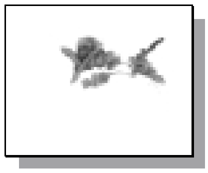
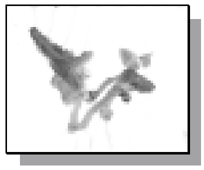
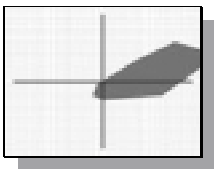
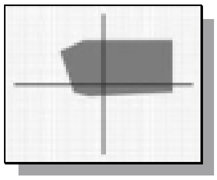
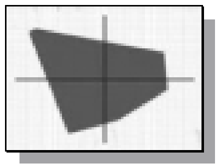
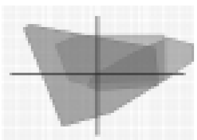
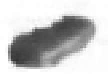
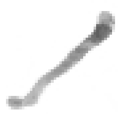
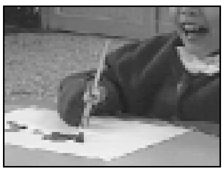
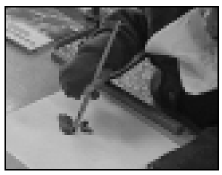
4.1. Experimental method

The experiment was performed with the permission of both the subject and her teacher. The experiment was initiated a total of three times. First, the T-shaped stick and T-shaped band were used as the assistive devices, then the hand-grip assistive device alone was used, and finally, the hand-grip assistive device and arm support assistive device were employed simultaneously. The surroundings and the desk and chair used in the experiment were identical to those used by the subject in daily classes. The experiment lasted for 20 minutes each time and during each experiment the subject was allowed to draw at will on a piece of A4 paper. The subject was permitted a 20 minutes break between each experiment. The drawing process was recorded on video camera to enable the creation of a detailed record.

4.2. Measurement

Following the above three experiments, this study used Corel Draw 9.0 graphics software to process the pictures into 5 mm square diagrams, then sketched the outline of the pictures, and located the axis and centre of each diagram. Table 4 lists the experiment results.

Table 4
Experiment results

Experiment equipment	Before using new assistive device	Using hand-grip assistive device	Using hand-grip and arm support assistive devices
Drawing results			
Square diagrams			
Agility (range covered) 	Horizontal distance: 163 mm Vertical distance: 80 mm centre: (65,15) mm	Horizontal distance: 168 mm Vertical distance: 75 mm centre: (18,12) mm	Horizontal distance: 208 mm Vertical distance: 155 mm Center: (-3,-12) mm
Stroke	Mostly dots	Dots and lines	Mostly lines
Distance (the longest line)	 18 mm	 52 mm	 133 mm
Posture	 Ulnar deviation Palmar flexion Wrist elevation	 After drawing in a normal posture for a period of time, arm rest against the table and restricted the drawing range	 Normal drawing posture
Stability	After ten minutes, drawing speed slowed and hand tremors began.	After thirteen minutes, drawing slowed down and the arm began to rest on the desk.	Hand and arm resting stably on arm support.

4.3. *Subjective rating*

Verbal questioning and video image observation revealed that the subject was more satisfied with using the "hand-grip assistive device" and the "arm support assistive device" simultaneously, as specified in the third experiment.

Table 5
Difference in upper limbs between the original and comparison experiment subjects

	Age (Years)	Body figure	Type of motor disability	Activity limitation
Original subject	Ten	Smaller than normal children	Mixed type	1. Muscle tension prevents the arms from being straightened or raised over the shoulders. 2. Finger weakness means that both of the index and the middle fingers need to be used when holding a pencil. 3. Extreme rigidity in the left arm.
Comparison experiment subject	Seven	Normal	Spastic Type	1. Muscle tension prevents the arms from being straightened or raised over the shoulders. 2. Training can allow the hand to grip pens.

4.4. Expert rating

After the experiment, the teacher of the subject child observed that the use of the "arm support assistive device" had increased the range of drawing and improved the strokes.

4.5. Comparison experiment

To further clarify the application of this assistive drawing device, a comparison experiment was performed. The subject was a seven year old female. She suffers from Cerebral Palsy with spastic type motor disability. The subject was unable to raise her stiff upper limbs owing to motor retardation, and could not walk because of severe lower limbs paralysis. Intellectual development was delayed. Moreover, the subject had limited activity range because of muscle spasm, though she could grip pen by training. Table 5 lists the difference in upper limbs between the original subject and the comparison experiment subject. The comparison experiment design was identical to that involving the original Cerebral Palsy subject, except that the fourth time of experiment procedure by using the hand-grip, arm support assistive devices and moving drawing board together was added. Table 6 lists the drawing results.

From Table 6, the picture drawn before using new assistive device was centered in the lower half of the paper, but the drawing ranges using the 'hand-grip assistive device', 'hand-grip and arm support assistive devices' and 'hand-grip, arm support assistive devices and moving drawing board' were broader. This finding resembles the result of the original case study. Analysis of strokes, dots and lines reveal that the four pictures are similar, but the picture drawn using the arm support assistive device and moving drawing board is more scattered and disorderly, possibly owing to unfamiliarity with the assistive drawing devices. Moreover, analysis of posture reveals that the body inclines forward before using the new assistive device and after using the hand-grip and arm support assistive devices. In contrast, the body assumes a straight posture when using the moving drawing board. Consequently, the design of the moving drawing board allows the drawing paper to approach the subject more closely, thus preventing the body from inclining forward while drawing.

5. Discussion

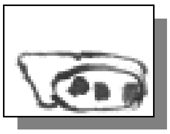
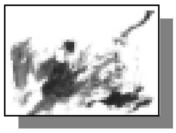
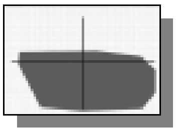
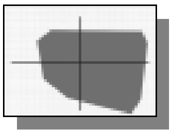
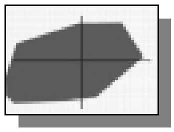
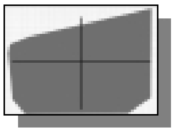
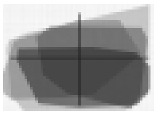
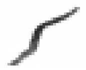
Through task analysis, product design and experiment, this case study has reached three concrete findings regarding the design of assistive drawing devices for Cerebral Palsy children with upper limbs disabilities, as discussed below.

5.1. Assistive drawing device design should begin from the analysis of drawing movements

From the square analysis diagrams in Table 4, the drawing ranges are similar for the first stage of the experiment (before using new assistive device) and the second stage of the experiment (after using the hand-grip assistive device). Consequently if assistive drawing device design is focused only on the hand of the user, the drawing range may not increase significantly. However, from the perspective of the centre point of the diagrams, drawing range approaches the centre of the paper when the "hand-grip assistive device" is used. The reason for this phenomenon may be the hard U-shaped wrist pad within the glove, which corrects the ulnar deviation of the subject while drawing.

Table 4 reveals that the experiment involving both the hand-grip and arm support assistive devices achieves better performance than the other two experiment procedures in terms of drawing range and drawing centre. This superior performance is mainly because the arm support assistive device increases arm agility thus allowing the user to save energy when extending the arm. Moreover, from Table 6, using the moving drawing

Table 6
Comparison experiment results

Experiment equipment	Before using new assistive device	Using hand-grip assistive device	Using hand-grip and arm support assistive devices	Using hand-grip, arm support assistive devices and moving drawing board
Drawing result				
Square diagrams				
Agility (range covered) 	Horizontal distance: 258 mm Vertical distance: 120 mm Centre: (5, -40) mm	Horizontal distance: 215 mm Vertical distance: 162 mm Centre: (22, -20) mm	Horizontal distance: 268 mm Vertical distance: 155 mm Centre: (-15, -5) mm	Horizontal distance: 280 mm Vertical distance: 210 mm Centre: (-5,0) mm
Stroke	Dots and lines	Dots and lines	Dots and lines	Dots and lines
Distance (the longest line)	 172 mm	 164 mm	 131 mm	 125 mm
Posture	 The body inclined forward.	 The body inclined forward.	 The body inclined forward.	 The body assumed a straight posture.

board allows the drawing paper to approach the subject more closely, thus preventing the body from inclining forward while drawing. From the above findings, this study concludes that, regarding the design of assistive drawing devices for Cerebral Palsy children with upper extremity disabilities, consideration of hand grip, arm movements and body posture is suggested if drawing movement is to be improved.

5.2. Arm support prevents fatigue while drawing

Because of various disabilities involving muscle contraction, Cerebral Palsy children are more easily fatigued than others when drawing. Observation reveals that drawing speed slows and the original subject suffers from trembling or needs to rest the arm on the desk after a short period of drawing without the arm support assistive device. For Cerebral Palsy children with extremely weak arms, the design of arm support assistive devices can improve stability while drawing and thus relieve arm fatigue.

5.3. Enhance drawing range and method of expression

The symptoms of motor disabilities in the upper limb limit the subject drawing range and method of expression by forcing the subject to draw mostly in dots.

However, the new assistive drawing device design may provide another method of expression by enabling the original subject draw with lines, allowing to draw freely and increase the drawing range. In the comparison experiment, the new assistive drawing devices also extend the drawing range and improve drawing centre.

6. Conclusion

Cerebral Palsy children may suffer from multiple handicaps besides motor disability. More and more assistive devices are being designed to help Cerebral Palsy children to improve their quality of life. Besides communicating pen devices, assistive drawing devices can also help Cerebral Palsy children to enhance physical and mental contentment.

This study reforms the assistive drawing device from the perspective of ergonomic design, which has received less attention before now. From the experiments, the assistive drawing device design is effective in terms of drawing movement and drawing range. Owing to the marked variation in behavioral capabilities among Cerebral Palsy children, this assistive drawing device design performed by the case study method may not be applicable to all Cerebral Palsy children. However, this design may be helpful for children with the same type of disabilities over the upper extremities and who require assistive devices for writing or drawing. We hope that this case study can provide a reference for future drawing aid designs.

Acknowledgements

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