Rehabilitation apparatus design and development by using ergonomic and physical principles

Lan-Ling Huang* and Dengchuan Cai

 NATIONAL YUNLIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, GRADUATE SCHOOL OF DESIGN DOCTORAL PROGRAM
 *g9630806@yuntech.edu.tw

Abstract: The study aimed to develop a synthetic product for arm rehabilitation which was designed by using ergonomic concept and economical consideration through a serial procedure of product design. Because a rotation movement consists of a horizontal and a vertical movement therefore it was applied to substitute for repetitive single horizontal and vertical movements. The features of the product included: 1) the adjustable length of the rotating arm was designed with the Taiwanese dimension ranging 250-750mm, 2) the product can be used on any plane (transverse, crown or sagittal plane) for multidimensional training, 3) a brake system provided adjustable friction forces for different levels of rehabilitation needs, and 4) due to small volume, the product was portable increasing probability of therapy in different locations. The study results can be a reference for designing a similar rehabilitation product.

Key words: Rehabilitation, Therapy, Product Design

1. Introduction
The health care for the aging has been a popular considered issue. With the growth of ages, the physical condition degenerated so that the diseases were possibly produced. According to the analytical report (Kung, 2008), Cerebrovascular Disease has become the top three causes of death in America. In Taiwan, Cerebrovascular Diseases also occupied the third cause of death for the year 2007 (Department of Health, Executive Yuan of R.O.C., 2008). It is also still a main cause contributes to the stroke.

Upper-extremity motor deficit is one of the main symptoms for the stroke patients (Gowland et al, 1992). About 85% stroke patients have function impairment on upper-extremity at the beginning stage of the stroke, and still about 40% patients have function impairment at the final stage of stroke (Mcarea et al, 2002). Some common upper-extremity symptoms of stroke patient are feeble muscle strength, unnatural synergies, and deficit in coordination within the joints. (Levin et al, 1996). In order to recover the function for daily life, the rehabilitation therapy is needed for the stroke patients. During the rehabilitation therapy, the doctor need to diagnose the stroke level of each stroke patient, then selected a suitable therapy product for rehabilitation to restore their movement function. A good rehabilitation product can increase the therapy performance and do therapy by themselves.
In many cases, people with Cerebrovascular Disease may cause motor disturbances in one side of the body. The symptom is referred to as hemi paresis (Sawner & LaVigne, 1992). For the hemiparesis patients, the extremity on unaffected side would function formally. Therefore, using unaffected extremity to promote the affected extremity for restoring its lost movement ability has been conducted and proved in many studies (Steenbergen et al, 1996; Mudie & Matyas, 2000; Cunningham & Stoykov, 2002). Various studies have applied the theory to rehabilitation therapy, for example, Steenbergen et al. (1996) examined the unimanual and bimanual coordination in spastic hemiparesis in which the subject is required to stretch his/her two hands forward to grasp small balls and subsequently place them into holes. The result showed that 92% of difference between hands was eliminated in the bimanual conditions. Mudie & Matyas (2000) had trained the hemiplegia patients in gripping action. The result showed the function of the affected hand increased grip power after training the pair-lateral hands. Cunningham & Stoykov (2002) tested the affected hand performance with bilateral hands and unilateral hand training. The result showed that the performance of the affected hand training with pair-lateral hands was better than with unilateral hand.

The theory for using an upper extremity on the unaffected side of the body to facilitate the other extremity on the affected side to recover its original movement ability for the stroke patients has been proposed and verified in various experiments and products. Similar to the above theory, using the unaffected muscles to facilitate the affected muscle in the same extremity to recover its lost movement ability was proposed by the study. The idea is that suppose the affected muscle has lost its movement ability along the Y-axis direction and the unaffected muscle is still able to move along the X-axis direction. Let the patients move their arms along a circular route, the unaffected muscle exercises a force \( F \) to move the arm from point A to point B which made an angle of \( N \) between line AB and X-axis, then the affected muscle will be driven by a component force \( F_y = (F \times \sin(N)) \) along Y-axis, and the hand will be forced to move to point B (Fig. 1). Therefore, the affected muscle will be trained by the component force \( F_y \) which will facilitate its movement ability along the Y-axis direction. When the circular movement continues, the movement ability of the affected muscles will be drilled and progressed continuously.

For the left-rightward movement (adduction and abduction) of the arm, eight muscles activate collaboratively, among them are Latissimus dorsi, Teres major, Trapezius, Rhomboideus major and minor, Deltoid, Pectoralis major, Supraspinatus, and Coracobrachialis. For the up-downward movement (extension and flexion of shoulder), five muscles activate collaboratively, they are Trapezius, Rhomboideus major and minor, Serratus anterior, Pectoralis minor, and Levator scapulae. For the for-backward movement (extension and flexion of elbow), seven muscles activate collectively, among them are Teres major, Deltoid, Serratus anterior, Biceps brachii, Brachialis, Brachioradialis, and Triceps brachi (Table 1) (Hoke & Koos, 1991). When doing a circular movement in coronal plane which includes left-rightward movement and up-downward movement, therefore eleven muscles work collectively. Doing a circular movement in sagittal plane which includes up-downward movement and for-backward movement, therefore eleven muscles work collectively. Doing a circular movement in transverse (horizontal) plane which includes left-rightward movement and for-backward movement, therefore thirteen muscles work collectively.

The current study aimed to design a rehabilitation product for hand therapy which use the above theory and take human factors into consideration.

2438
Fig. 1. Illustration for using unaffected muscle to facilitate the affected muscle.

Table 1. The muscles that move the arm in different directions (Hoke & Koos, 1991)

<table>
<thead>
<tr>
<th>No</th>
<th>Muscles that move the arm</th>
<th>Left-rightward movement</th>
<th>Up-downward movement</th>
<th>For-backward movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Latissimus dorsi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Teres major</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Trapezius</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Rhomboideus major and minor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Deltoid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Pectoralis major</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Supraspinatus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Coracobrachialis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Serratus anterior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pectoralis minor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Levator scapulae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Biceps brachii</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Brachialis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Brachioradialis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Triceps brachii</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Investigation for the current rehabilitation equipments

The current study investigated various rehabilitation equipments in many hospitals in Taiwan. Analytical results could be summarized as following:
2.1 Simple products in hospitals

Most six frequently used products in hospitals in Taiwan were listed below. The functions and movements types of the equipments were also analyzed as well.

(1) Arm/hand skate: the main function of the arm/hand skate is to develop upper and/or forearm extremity strength and endurance of the patients (see Fig. 1). The main movement direction was horizontal from left to right and reversed.

(2) Climbing board and bar: the main function of the climbing board and bar is to develop upper extremity strength and endurance of the patients in the vertical direction. (see Fig. 2). The main movement direction was vertical from bottom to top and reversed.

(3) Resistive pinch exerciser: the equipment is to develop upper extremity with hand strengthening and coordination of the patients (see Fig. 3). The main movement direction was vertical from bottom to top and reversed.

(4) Vertical ring tree: the equipment is to develop eye and hand coordination, manipulation, endurance and sequencing (Fig. 4). The main movement direction was vertical from bottom to top and reversed.

(5) Single curved shoulder arc: Crossing the highest and lowest point to develops pinch strengthening and eye/hand coordination. The main movement direction was horizontal from left to right and reversed.

(6) Incline board: the equipment is to makes shoulder extension easier. The main movement direction was vertical from bottom to top combining with horizontal from rear to the front and reversed.

The study concluded that the main movement direction of the six equipments could be summarized as: 1) horizontal from left to the right and reversed, vertical from bottom to top and reversed, horizontal from rear to front and reversed, and arc movements. 2) most of the equipments were old and outdated. 3) there was no indicator for showing degree of the rehabilitation.
2.2 Rehabilitation equipments survey

We also surveyed many imported equipments and got understanding functions of them. There are four main products including (1) Anatomical Shoulder CPM (Continuous passive motion) Machine, (2) Centura Elbow Module (CEM), (3) Calibrated Shoulder Wheel, and (4) Shoulder Slide. The movement function included shoulder, elbow and wrist flexion to extension, adjustable pronation and supination. Adjust functions were speed and resistance (Fig. 7-10).
3. Design Processes

After analyzing the domestic products in the hospitals and the import equipments, the design objectives were formulated. A systematic design process was then followed to create the rehabilitation product.

3.1 Rehabilitation equipments survey

The design objectives included 1) the users were set for the second to third level of the stroke patients. The upper extremity of the second level patient has few functions and the upper extremity and fingers have few functions and are able to bend. 2) the product needed to provide a function for carrying. 3) the movements should be included flexion and extension, abduction and adduction, upper to bottom and reversed and rotation. 4) the product should provide the functions, for example, adjustable resistance and operation angle.
3.2 Design features

The main sizes of the parts of the product were designed to fit the body dimension measurements of Taiwanese. The range of rotation radius was designed with the hand length aging from 20-60 year. The lower limit was 525mm adopting the female dimension of 64 years and the upper limit was 685mm adopting the male dimension of 20 years (Wang et al., 2002).

The rotation bar has three segments. Each segment was 250mm which was a half hand length of female. Therefore the adjustable range was 250-750mm (Fig. 12). This allows subject to adjust to fit their arm length. The product also designed with a scale for recording the recovery condition of the patient (Fig. 13). Furthermore, the product could be set on a table and could be operated along crown, sagittal, or transverse plane for rehabilitation therapy (Fig. 14-17).

A brake mechanism was designed on the rotation shaft providing adjustable friction forces for different levels of rehabilitations (Fig. 18). The handle was design to fit the hand style and size of the Taiwanese (Fig. 19). In addition, the volume of the product was small so that it could be carried easily. This design was evaluated by three occupational therapists and got a high repetition.
4. Conclusion and suggestion
The current study investigated the domestic rehabilitation products in hospitals in Taiwan and found that: 1) the rehabilitation products were old and outdate and did not provide the function for recording the recovery situation of the patients. 2) the import products were expensive. According to the investigation results, we formulated the design objectives: 1) the adjustable functions included speed, pause, and strength. 2) the movement functions included flexion and extension, abduction and adduction and rotation. Followed the design objective, the product was designed by the current study with the following features: 1) the rotation bar of the product was adjustable and designed to fit the body dimension of Taiwanese. The adjustable range was 250-750mm. 2) the product could be set on a table and be operated along crown plane, sagittal plane or transverse plane. 3) the product was designed with a brake mechanism providing resistance adjustment. The results could be a reference for rehabilitation product design.

5. Acknowledgment
The authors would like to thank the Ministry of Education of the Republic of China (Taiwan) for financially supporting the author to participate the conference.
6. References


