APPLICATIONS OF CONCURRENT SYSTEMATIC DESIGN ON ASSISTIVE TECHNOLOGY-- A NEW WHEELCHAIR DESIGN FOR STROKE PATIENT

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Abstract: Some market-oriented approaches are adopted in development of assistive related devices now, but most of them could not really obtain original requirements and concerns of users, designers, and clinicians simultaneously. The purpose of this study is to develop a customized wheelchair for people with hemiplegia through a systematic process by integrating empirical study and analytic hierarchy process (AHP) method. A cross-field team participates in whole procedures to make the design process more objective and transparent. The results showed a total of 11 important factors of wheelchair design for hemiplegic individuals and classified into four categories according to properties: (a) operation, (b) ergonomics, (c) function and (d) quality. Through concept design based on the user requirements and experts' opinions by professional team, the newly manual wheelchair specifically for patient with hemiplegia was fabricated.

Introduction

Direct user investigation has widely applied to the assistive technology field, and it is apparent that many assistive device factories now would rather adopt more commercial oriented approach to develop product than a purely engineering perspective. Companies of assistive device are generally aware of the importance of understanding customers' desires, but most of them are not skilled in obtaining such information from users or getting user feedback about the comments of their products. The lack of inspection of consumer opinion and changing their needs were fateful factors for assistive device abandonment.

Product planning plays an important role to improve efficiency and meet modern demands. There are several factors changing the way, including the increasing complexity of designs requiring cooperation between experts in many engineering fields and the need to provide more services with reducing health care fees [1][2]. These influences have encouraged engineers to improve the design process by adopting a multifunction approach to focus on the requirements of the consumers [3][4][5].

Traditional manual wheelchair has been widely adopted throughout persons with healthy upper limbs who are unable to move by themselves. The previous researches have pointed out that over 80% of manual wheelchair users got upper limbs injuries, especially in shoulder and elbow, and accumulated disease such as carpal tunnel syndrome (CTS) [6][7][8]. Due to well stability, wheelchair is an important mobility aid of daily life for people with physiological defects. It is also common in many other conditions, including hemiplegia, balance problems arising from sensory or cerebellar maladies. Hemiplegia caused by cerebrovascular accident (CVA) to lose ability of movement independently. For such individuals, users have no good alternative from the existed wheelchairs at present.

In our clinical experiences, most manual wheelchair users with hemiplegia use their unaffected arm and leg to impel wheelchairs. The asymmetrical forces, however, may cause the wheelchair to deviate toward the affected side. There are numbers of studies focus on wheelchair propulsion; however few have included stroke individuals [9][10].

The purposes of this study is to integrate a systematic design method including empirical study and analytic hierarchy process (AHP) method to analyze the requirements of hemiplegic patients and providing customized wheelchair for them.

Materials and Methods

In this study, a systematic process includes empirical study and AHP were employed to refine the wheelchair design for patients with hemiplegia. Observation, interview and questionnaire are included in empirical study. Direct observation and in-depth interview are implemented to observe the operation of traditional wheelchair of the patients and analysis their propulsion characteristics. After discussion, the questionnaire was established refer to observation and interview. The item with higher score, was defined as important factor, means more important from users' opinion. Although the important factors just considering the user requirements was determined from questionnaire survey, the opinions from engineers, designers, therapists and clinicians were not taken in design process. Thus the order of important factors from questionnaire will be re-ranked via AHP to consider those professionals' opinions by simple pairwise comparison and then to

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develop priorities in hierarchy. Using AHP in solving a decision problem involves three steps [11].

Step 1: Structure a hierarchy of the criteria that influence the behavior of the problem.

Step 2: Calculate the vectors of priorities between levels. In this step, three phases are contained.

(i) Construct a pairwise comparison matrix. Let C1, C2,⋯, Cn be the set of activities. The quantified judgments on pairs of activities Ci, Cj are represented by and n n matrix

A= (aij), i, j= 1, 2, 3,…, n. (1)

Rule 1: If aij = , then aij =1/ , 0.

Rule 2: If Ci is judged to be of equal relative importance as Cj , then aij =1, aji =1; in particular, aij =1 for all i. Thus the matrix A has the form

$$A = \begin{bmatrix} 1 & A12 & \dots & A1N \\ 1/A12 & 1 & \dots & A2N \\ \dots & \dots & \dots & \dots \\ 1/A1N & 1/A2N & \dots & 1 \end{bmatrix} \quad (2)$$

(ii) Evaluate the vectors of priorities and overall priority vector.The method of "normalization of the geometric mean of the rows (NGM)" for the solution is usually used to estimate the vectors of priority or weighting functions. The formula is shown as follows:

$$wi = \left(\prod_{j=1}^{n} aij\right)^{1/n} \Big/ \sum_{i=1}^{n}\left(\prod_{j=1}^{n} aij\right)^{1/n},$$

i, j = 1,2, …, n. (3)

(iii) Evaluate the consistency.The consistency ratio (C.R.) was used to estimate the consistency of the judgments of the participants. The C.R. is defined as Saaty [11].

$$C.R.= {C.I.}/{R.I.} \quad (4)$$

Where C.I. is called as consistency index which is defined as

$$C.I.= {\lambda_{\max} - n}/{n-1} \quad (5)$$

Where "λmax" represents the maximum or principal eigenvalue of the pairwise comparison matrix and "n" represents the number of activities in the matrix. The result is the closer "λmax" to the "n" more consistent. The notation R.I. is the average random index. The average random indexes for different orders of matrices are given in Table 1. A C.R. of 0.10 or less is considered acceptable.

Table 1: Scale of relative importance of AHP

Order	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
R.I.	1.24	1.32	1.41	1.45	1.49	1.51	1.53	1.56

Step 3: After the consistency of judgments is assured, the best alternative can be selected according to the evaluated overall priority vector obtained in phase (ii) of step 2.

Results

After the fervent discussion of both observation and interview, a questionnaire survey was performed. The first 30% of all items consist of 11 items, which were taken as important factors for concept design of new wheelchair. The 11 important factors of wheelchair design for hemiplegic individuals are classified into four categories according to properties: (a) operation, (b) ergonomics, (c) function and (d) quality (shown as Table 2). The highest score of top five items are "comfortable", "effort saving", "wheelchair dimension", "portable" and "injury".

Table 2: Four categories of 11 important factors

Properties	**Items**
A. Operation	1 Injury
	2 Effort saving
	2 Turn round
	4 Efficiency
	5 Steering
	6 Long term use
B. Ergonomics	7 Wheelchair dimension (W/C Dim)
	8 Suitable
	9 Comfortable
C. Function	10 Portable
D. Quality	11 Price

Based on the important factors from the questionnaire survey, AHP method was used to re-analyze these 11 important factors by adding those experts' opinions on AHP matrix. The pairwise comparison matrix was obtained from the group's quantified judgments. Table 3 shows the final AHP matrix and we can find the original order of the 11 important factors was changed.

The λmax for the matrix in Table 2 is 12.06. This gives (12.06-11)/ (11-1) =0.106 for the C.I., that was defined in Eq. (5). To determine how good on this result is divided it by the corresponding value of the random index for a third order matrix (R.I.=1.51, Table 1). The C.R. defined in Eq. (4) is 0.106/1.51=0.07 that is less than the acceptable value (0.1).

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Table 3: Judgment matrix of important factors from AHP

	Injury	Effort saving	Turn round	Efficiency	Steering	Long term use	W/C Dim.	Suitable	Comfortable	Portable	Price	Weighting %
Injury	1	1/9	1/3	1/5	1/3	3	1/7	1	1/9	1/5	1/7	1.98
Effort saving	9	1	5	3	3	7	1	5	1	3	1	16.44
Turn round	3	1/5	1	1/3	1/2	3	1/7	1	1/7	1/5	1/5	2.93
Effici-ency	5	1/3	3	1	1	5	1/3	3	1/5	1	1/3	6.54
Steer-ing	3	1/3	2	1	1	3	1/5	3	1/5	1/3	1/3	4.96
Long term use	1/3	1/7	1/3	1/5	1/3	1	1/7	1/3	1/9	1/5	1/7	1.50
W/C Dim.	5	7	7	3	5	7	1	5	1	3	1	20.09
Suita-ble	1	1/5	1	1/3	1/3	3	1/5	1	1/7	1/5	1/5	2.63
Comfo-rtable	9	1	7	5	5	9	1	7	1	3	1	19.62
Porta-ble	5	1/3	5	1	3	5	1/5	5	1/3	1	1	8.76
Price	7	1	5	3	3	7	1	5	1	1	1	14.54

The concept of ARM-LEG PROPULSION wheelchair was addressed, in which arm propel one wheel and leg propel the other one. The power input of this concept was similar to traditional manual wheelchair. Hemiplegic patients may use the unaffected arm to propel the wheel on the same side, and use the unaffected foot to impel the other wheel by pedaling a four-bar-linkage system that was constructed on the unaffected side. The concept was shown in Figure 1.

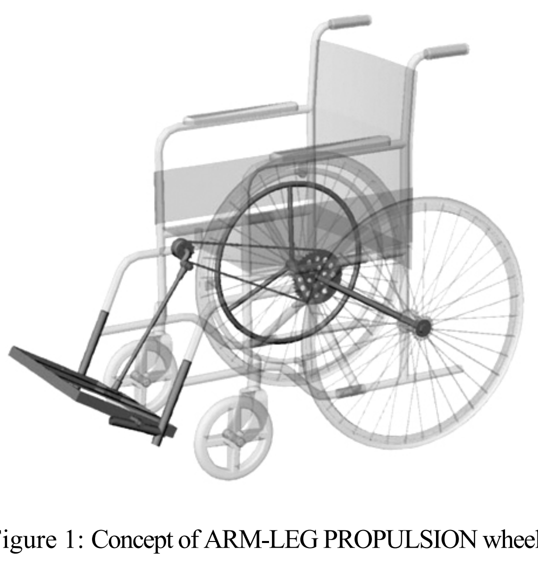

Figure 1: Concept of ARM-LEG PROPULSION wheelchair

Meanwhile, users may use the other hand rim and also set on the unaffected side to provide extra power for the wheel on the affected side when the four-bar-linkage system was at dead point. The advantages of this concept are patients can use both arm and leg to propel wheelchair that provides plenty of power supply and reduces upper limbs injuries caused by overuse.

Discussion and Conclusion

The analysis of user requirement is the key factor to new wheelchair development. The direct participation of users provides important guidance during the design process is a key issue to find out what the practical problems are already with used technology and which problems have not been addressed by now.

In this study, a customer-oriented and systematic method was presented to develop a new manual wheelchair for people with hemiplegia. The AHP is a well-known technique for product development that decomposes a problem into several levels in such a way, and then they formed a hierarchy [11]. The first factor and the last one of the 11 important factors form are "comfortable" and "long time use" respectively. However the order is changed after the operation of AHP method, the first factor is replaced as "wheelchair dimension" (Table 4). Because the result from questionnaire survey is just considering users' opinions, the final decision of concept design will lack the professionals' suggestions if the process only follows the result of questionnaire survey in the phase. The specific benefit of AHP method is that the decision of pairwise was made by the professionals, it means the weighting calculation involves both of users' and professionals' opinions. The result shown in Table 4 also represented that after AHP process, the scale of those11 important factors is larger than the scale from questionnaire survey.

Table 4: Comparison of the rank of important factors between using AHP and without AHP

Important factors	**By AHP**		**Without AHP**	
	Rank	**(%)**	**Rank**	**(%)**
W/C Dim.	*1*	20.09	3	3.85
Comfortable	*2*	19.62	1	3.97
Effort saving	*3*	16.44	2	3.93
Price	*4*	14.54	5	3.74
Portable	*5*	8.76	4	3.76
Efficiency	*6*	6.54	9	3.68
Steering	*7*	4.96	9	3.68
Turn round	*8*	2.93	7	3.70
Suitable	*9*	2.63	7	3.70
Injury	*10*	1.98	5	3.74
Long term use	*11*	1.50	11	3.66

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The prototype of ARM-LEG PROPULSION wheelchair was fabricated, shown as Figure 2. According to the physical characteristic of stroke patient, the users may use the unaffected arm to propel the wheel on the same side, and use the unaffected foot to impel the other wheel by pedaling a four-bar-linkage system.

Figure 2: Prototype of ARM-LEG PROPULSION wheelchair

Propelling with the legs could be more efficient than with the arms, because the major muscles of the legs are working to produce movement. In the present research, the advantages of the concept are patients can use both arm and leg to propel wheelchair that provides plenty power supply in an efficient way.

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Acknowledgement

The authors would like to acknowledge the financial support from National Science Council under the contract number NSC 90-2213-E-218-019-.