Bulgarian Chemical Communications, Volume 49, Special Edition K1, (pp. 15 – 19) 2017

Evaluation of motor function based on self-correction analytical hierarchy process

X. Li [1*], X. Wang [1]

[1] *State Key Laboratory of Synthetical Automation for Process Industries, Northeastern University, Shenyang, Liaoning 110819, China*

Received August 1, 2017; Revised November 21, 2017

In the evaluation of clinical rehabilitation functions, different experts will have different views. In order to be able to consider the expert opinions, in this paper the contents and methods of upper limb motor function evaluation were studied, and the evaluation index system was established. Quantitative evaluation of the evaluation index of motor function was carried out, and different evaluation criteria were provided for different evaluation indexes. The method of SFAHP (Self-correction Fuzzy Analytical Hierarchy Process) based on elemental classification was used to evaluate the rehabilitation process of hemiplegia upper limbs. The hierarchical model and evaluation system of evaluation index were established, and the evaluation model of hemiplegia upper limb motor function was established. Systematic analysis method was used to evaluate the feasibility and effectiveness of SFAHP method in the evaluation of upper limb rehabilitation. The evaluation results were consistent with the results of clinical motor function evaluation.

Key words: Motor function evaluation, Self-correction AHP, Evaluation system, Evaluation model.

INTRODUCTION

The clinical results show that the motor function is the main index to reflect the effectiness of rehabilitation [1, 2]. Therefore, the motor function is important for the hemiplegic treatment and is also crucial for rehabilitation evaluation. In the rehabilitation of the stroke, the training of motor function will be influenced by the personal factors of different therapists and the treatment effect mainly depends on physicians' experience and qualifications [3-5]. Moreover, the rehabilitation level is mainly judged by physicians' clinical experience. Currently, no rehabilitation system can completely replace the therapists in evaluating the rehabilitation level.

This paper reviews and compares all aspects (physical activities and daily activities, etc.) involved in the dyskinesia of hemiplegic upper-limb patients, as well as the current status and potentials of the motor function. Given the differences of experts' evaluation towards rehabilitation, this paper first combines the analytical hierarchy process (frequently used in the decision-making analysis) with the fuzzy analysis method. Then this paper proposed a systematic evaluation method, which is qualitative-and-quantitative and is used for SFAHP (Self-correction Fuzzy Analytical Hierarchy Process) based on element demarcation.

In this paper, an upper-limb rehabilitation robot system was used to determine the index system of the motor function evaluation and formulate the evaluation standards of all evaluation indexes. Finally, this paper establishes a comprehensive model for evaluating the motor functions of the hemiplegic upper-limbs to test and evaluate the rehabilitation effects of the affected limbs and the grades of the motor functions.

SFAHP-BASED EVALUATION OF THE HEMIPLEGIC UPPER-LIMB MOTOR FUNCTIONS

Main contents in the evaluation of clinical motor function

The dyskinesia is the typical external pathological sign in the stroke. After stroke the dyskinesia symptoms of the hemiplegic patients are mainly dystonia, coordination disorders between muscle groups, and abnormal reflex activities, namely, the motion forms of associated movement, associative reaction and spinal level of tonus reflex [6-7]. The goal of the motor function rehabilitation is to change the abnormal motor patterns of patients, reduce cramp symptoms and guide patients in improving the muscular tension and effectively controlling the movement. In the clinical treatment, four aspects are mainly used to evaluate the motor functions: muscle strength, joint motion degree, equilibrium function, and coordination function [8-11].

Upper-limb rehabilitation robot

The upper-limb rehabilitation robot (Figure (1), Rehabilitation robot structure) has a mechanical arm, an arm holder, and a base. As an executing agency, the robot receives and performs the tasks and guides patient's affected limbs in conducting

To whom all correspondence should be sent:
E-mail: lixing8245@163.com

the training practices of different modes or different intensity. According to the evaluation results of the hemiplegic patients or their affected limbs, the rehabilitation training mode is selected for the following stage to remodel the brain functions and accelerate the rehabilitation.

Fig. 1. Rehabilitation robot structure.

SFAHP (Self-correction Fuzzy Analytical Hierarchy Process)

In this process, the testing functions of the upper-limb rehabilitation robot system can be used to measure the muscle strength and the ranges of joint motions. First, the test motions are set up, and then, the equilibrium function is evaluated in two aspects: the time and the direction for patients to complete the specified test actions. Regarding the coordination function, the same procedures are conducted to test the trajectory smoothness and consistency. The relationships between indexes used for evaluating the motor functions of hemiplegic upper-limbs are shown in Figure (2). SFAHP combines the quantitativeness and objectivity of AHP with the inclusiveness of the fuzzy comprehensive evaluation method [15-16]. Also, self-correction and circular comparison are adopted in the evaluation to remove extreme values and opinions of expert grading and revise the element scale of the judgment matrix. In this way, personal errors can be reduced in the evaluation.

EVALUATION MODEL OF THE MOTOR FUNCTIONS

Hierarchical structure of evaluation indexes

Layered decomposition and tree ordering are used to process the evaluation indexes of the motor functions and determine the factor set U of the rehabilitation evaluation index system:

$$U=\{u_1, \quad u_2, \quad u_3\}$$

where, u_1 is the evaluation of muscle strength and joint motion range in $u_1=\{u_{11},u_{12}\}$, u_{11} is the level of muscle strength, and u_{12} is joint motion range.

u_2 is the equilibrium function evaluation in $u_2=\{u_{21},u_{22}\}$, u_{21} is motion degree in the correct direction, u_{22} is specified motion time; u_3 is coordination function evaluation in $u_3=\{u_{31},u_{32}\}$, u_{31} is smoothness of the motion trajectory, and u_{32} is the consistency of the motion trajectory. The hierarchical structure of the index system for evaluating the hemiplegic upper-limb motor functions is shown in Figure 3.

Index evaluation standards [17]

Different from the methods used for evaluating clinical motor functions, this method uses the data collection of the upper-limb rehabilitation robot, quantifies the evaluation method of the hemiplegic upper-limb motor function indices, and provides the standards of all evaluation indices. The evaluation standards of all indices are as given in ref. [17].

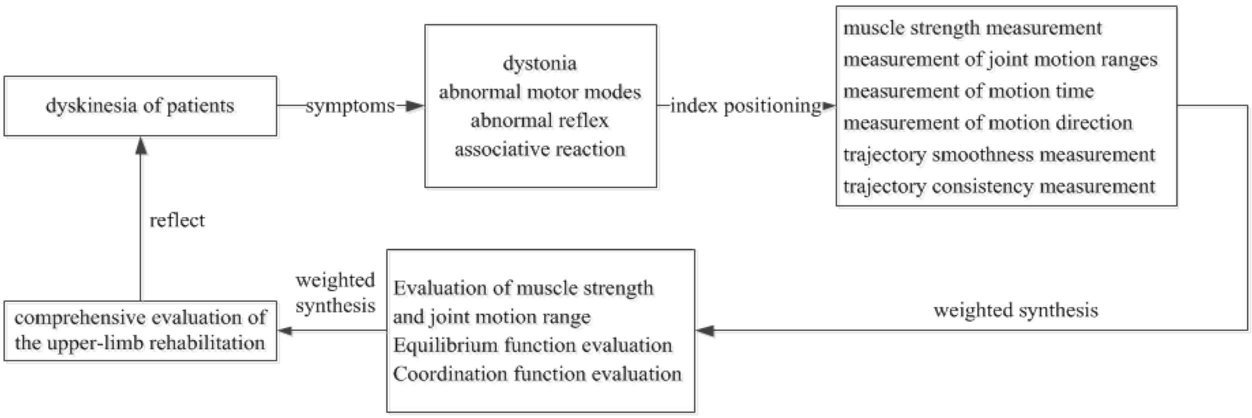

Fig. 2. Diagram of upper limb rehabilitation robot rehabilitation evaluation index.

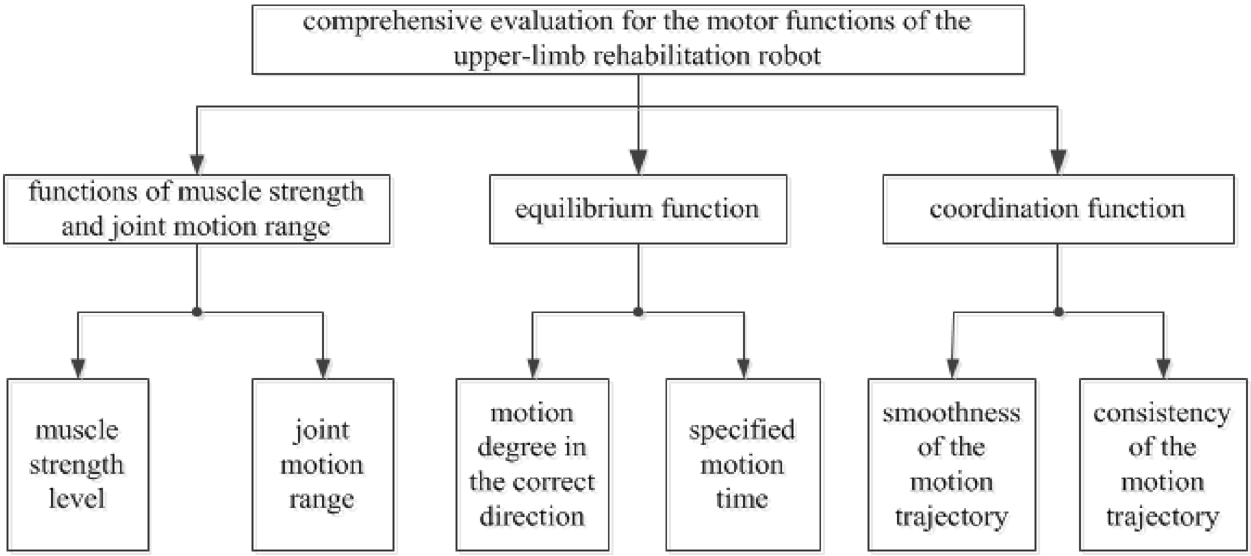

Fig. 3. Hierarchical structure of the motor function index for the upper-limb rehabilitation robot

Construct the commented system

Five comments are established to evaluate the motor function of the hemiplegic upper limbs: excellent, good, moderate, acceptable, and poor. These comments are used to represent the rehabilitation effects of the hemiplegic upper-limb motor functions and the comment set of the motor function evaluation is

$$V=\{v_1,v_2,v_3,v_4,v_5\}$$

Among these comments, v_1 is excellent with scores between 90 and 100; v_2 is good with scores between 80 and 89; v_3 is moderate with scores between 70 and 79; v_4 is pass with scores between 60 and 69; v_5 is pass with scores between 50 and 59.

Determination of the weight coefficient

Scale evaluation: Three clinical rehabilitation physicians were invited to form the expert group and then all layers of elements were through the scale evaluation in the form of questionnaires, designed on the basis of AHP. The importance of influence factors was pairwise compared and the measurement scales were divided into five grades: important , very important, fairly important, slightly important, and equally important, which respectively correspond to the values of 9, 7, 5, 3, and 1. The measurement scale near the left means that the factors in the left column are more important than those in the right column, while the measurement scale near the left means that the factors in the right column are more important than those in the left column.

Establishing the subordinating degree function

Suppose the comment set V has five grades: v_1 means excellent with scores ranging from 90 to 100; v_2 means good with scores ranging from 80 to 89; v_3 means moderate with scores ranging from 70 to 79; v_4 means pass with scores ranging from 60 to 69; v_5 means pass with scores ranging from 50 to 59. This helps to determine the subordinating degree function for evaluating the motor functions of the upper-limb rehabilitation robot. In the equations $i=1,2,3$， $j=1,2$.

$$\mu_{v1}(u_{ij})=\begin{cases}1 & u_{ij}\geq 90\\ \frac{(u_{ij}-80)}{10} & 80\leq u_{ij}<90\\ 0 & u_{ij}<80\end{cases} \quad (1)$$

$$\mu_{v2}(u_{ij})=\begin{cases}\frac{(u_{ij}-70)}{10} & 70\leq u_{ij}<80\\ \frac{(90-u_{ij})}{10} & 80\leq u_{ij}<90\\ 0 & u_{ij}<70, or, u_{ij}\geq 90\end{cases} \quad (2)$$

$$\mu_{v3}(u_{ij})=\begin{cases}\frac{(u_{ij}-60)}{10} & 60\leq u_{ij}<70\\ \frac{(80-u_{ij})}{10} & 70\leq u_{ij}<80\\ 0 & u_{ij}<60, or, u_{ij}\geq 80\end{cases} \quad (3)$$

$$\mu_{v4}(u_{ij})=\begin{cases}\frac{(u_{ij}-50)}{10} & 50\leq u_{ij}<60\\ \frac{(70-u_{ij})}{10} & 60\leq u_{ij}<70\\ 0 & u_{ij}<50, or, u_{ij}\geq 70\end{cases} \quad (4)$$

$$\mu_{v5}(u_{ij})=\begin{cases}0 & u_i \geq 60\\ \frac{(60-u_{ij})}{10} & 50 \leq u_{ij} < 60\\ 1 & u_{ij} < 50\end{cases} \quad (5)$$

Establishing the model of comprehensive evaluation

According to the subordinating degree function listed above, all factors of the data are quantified. Through evaluating single factors, the single factor evaluation vector was established to construct the vague evaluation matrix.

The fuzzy comprehensive evaluation matrix of the motor functions for the upper-limb rehabilitation robot is

$$R_U=\left(B_{u_1}\quad B_{u_2}\quad B_{u_3}\right)^T=\left(W_{u_1}\circ R_{u_1}\quad W_{u_2}\circ R_{u_2}\quad W_{u_3}\circ R_{u_3}\right)^T$$
$$=\left[r_{ij}\right]_{3\times 5}=\begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15}\\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25}\\ r_{31} & r_{32} & r_{33} & r_{34} & r_{35}\end{bmatrix} \quad (6)$$

In the equations, the following condition is satisfied:

$$r_{ij}=\bigvee_{j=1}^{5}\left[W_{u_i}\wedge\mu_{vj}(u_{ij})\right]\ (i=1,2,3;\ j=1,2,3,4,5)$$

ALGORITHM VERIFICATION

The upper-limb rehabilitation robot was used to evaluate the motor functions of three patients with hemiplegic upper-limbs. In the evaluation, these patients wear mechanical arms and the body electrode patches of the surface electro-myogram signal collector are attached to different parts of the muscles. To ensure the accuracy of the evaluation, the patient performs three tests and the testing results are shown in Table 1.

In terms of muscle strength, the scores of the patient were 85, 85, and 83 in the three tests, respectively. According to equations (9)-(14), the following is obtained.

$$\mu_{v1}(u_{11})=\left[\mu_{v1}(85)+\mu_{v1}(85)+\mu_{v1}(83)\right]/3=0.43$$

$$\mu_{v2}(u_{11})=\left[\mu_{v2}(85)+\mu_{v2}(85)+\mu_{v2}(83)\right]/3=0.57$$

$$\mu_{v3}(u_{11})=\left[\mu_{v3}(85)+\mu_{v3}(85)+\mu_{v3}(83)\right]/3=0$$

$$\mu_{v4}(u_{11})=\left[\mu_{v4}(85)+\mu_{v4}(85)+\mu_{v4}(83)\right]/3=0$$

$$\mu_{v5}(u_{11})=\left[\mu_{v5}(85)+\mu_{v5}(85)+\mu_{v5}(83)\right]/3=0$$

The following equation can be obtained from equation (6)

$$B_{u_1}=W_{u_1}\circ R_{u_1}=(0.5000,0.5000)\circ\begin{bmatrix}0.43 & 0.57 & 0 & 0 & 0\\ 0.33 & 0.67 & 0 & 0 & 0\end{bmatrix}$$
$$=(0.43,0.5,0,0,0)$$

Similarly, $B_{u_2}=W_{u_2}\circ R_{u_2}=(0.23,0.75,0,0,0)$

$$B_{u_3}=W_{u_3}\circ R_{u_3}=(0.1,0.75,0,0,0)$$

The comprehensive evaluation result of the patient's motor functions is:

$$B_U=W_U\circ R_U=(0.1429,0.4286,0.4286)\circ\begin{bmatrix}0.43 & 0.5 & 0 & 0 & 0\\ 0.23 & 0.75 & 0 & 0 & 0\\ 0.1 & 0.75 & 0 & 0 & 0\end{bmatrix}$$
$$=(0.23,0.43,0,0,0)$$

The equation can be obtained through normalization.

$$B_U=(0.35,0.65,0,0,0)$$

CONCLUSION

From this, the overall evaluation result from the upper-limb rehabilitation robot can be obtained for judging the motor functions of hemiplegic patients. According to the principle of the maximum subordination degree, the patient is in good state of motor functions. Thus, it can be understood that the affected limbs of the patient have approximated the normal level. It can be seen that the curve for the SFAHP-based evaluation result of the motor functions is consistent with that of the clinical rehabilitation. It means that the evaluation result is correct and the method can be applied to evaluate the motor functions of hemiplegic upper-limb rehabilitation.

Table 1. Basic physical properties of high liquid limit soil.

	Muscle strength level	Joint motion range	Motion degree in the correct direction	Motion time of prescript actions	Motion trajectory smoothness	Motion trajectory consistency
1st test	85	84	83	80	81	80
2nd test	85	82	82	81	82	80
3rd test	83	84	82	80	80	81

Acknowledgements: *This work is supported by "Fundamental Research Funds for the Central Universities" (N1508040), 2015 Liaoning province Doctoral Fund (201501142) and National Natural Science Foundation of China (61503070).*

REFERENCES

1. W. Ma, *Chinese Journal of Clinical Rehabilitation*, **6**(7), 10 (2002).
2. Y. Huang, N. Wang, *Chinese Journal of Rehabilitation Medicine*, **11**(4), 185 (1996).
3. H. Miao, *Chinese Rehabilitation Theory and Practice*, **26**(3), 78 (1997).
4. Q. Yin, B. Sheng, F. Wang, *Chinese Rehabilitation Medicine Magazine*, **19**(3), 232 (2004).
5. J. Gu, H. Huang, H. Yu, *Journal of Chongqing Medicine*, **38**(8), 69 (2009).
6. Y. Zhu. Science of Neurological Rehabilitation. Beijing: People's Publishing House of Military Surgeons, **1**, 335 (2001).
7. A. Wang. Science of Rehabilitation Function Evaluation. Fudan University Press, 2009.
8. M. Mihelj, D. Novak, J. Ziherl, A.Olensek, M. Munih, *Assistive Technology*, **16**(1), 54 (2004).
9. L. Zhou, J. Shao. Stroke rehabilitation treatment: Evaluation of combined application of SGT-700 apparatus and fluoxetine, Proceedings of the 2011 International Conference on Human Health and Biomedical Engineering (HHBE), 343, 2011
10. K.Kubo，T.Miyoshi，A. Kanai, K.Terashima, *Journal of Robotics*, 348207 (14 pp.), (2011).
11. Z. Q. Sun. Medical Comprehensive Evaluation Method. China Science and Technology Press. 2014
12. Q.L. Li, T.M. Ye, Z.J. Du, *Journal of Harbin Engineering University*, **30**(2), 166 (2009).
13. X. J. Chen, L. Liang. Systematic Evaluation Methods and Applications. Press of Chinese Science and Technology University, 1993.
14. Y. Ye, L. Ke, D. Huang. Systematic Comprehensive Evaluation Technology and Applications. Metallurgical Industry Press, 2006.
15. F. Z. Li. Introduction to Dynamic Fuzzy Logic. Yunan Science and Technology Press, 2005.
16. Z. Cao, Dynamic Fuzzy Evaluation and Empirical Analysis of Libraries. Beijing Library Press, 2007.
17. X, Li, J. Wang, *Information-An International Interdisciplinary Journal*, **15**, 11A, 469 (2011)