Development of Motivative Exercise Device and Standardization Approach for Evaluation of Walk Ability in Disabled Elderly

Hajime Takada¹, TAKIZAWA Shigeo², Akira Iemoto², Yuusuke Komatsu³
¹Yokohama National University, ²Biophilia Institute, ³East Japan Railway Company

Abstract
An objective rating of walk ability is desired for efficient rehabilitation enforcement. We developed a measuring device in which reciprocating movement of cross direction and rocking movement based on the heel parts as a pivot are available based on US patent. Experimental trials using the device for the measurement of muscle function were done in volunteers. In a comparative study of their walk ability in normal daily living, it was confirmed that the angular speed in rocking movement had a close relation with the gait evaluation. It is expected to judge the walking ability automatically with using the device developed in the future by the study of a larger cohort of subjects.

Keywords: Motivative exercise, Effect evaluation, Device development, Angular speed

1. Introduction
This research was carried out in order to establish the parameters that standardize the effects of the motivative exercise for the programmed rehabilitation¹ named the TAKIZAWA method which was patented in the US to obtain positive results on disabled elderly attempting to reacquire the walking ability. In some nursing and personal care facilities for the fragile and disabled elderly in Japan, we confirm that patients with dysfunctions of lower extremities due to many kinds of primary diseases reacquired walk ability by the method ². A device of knee flexion and extension exercises (knee exercise) and another for the ankle dorsiflexion and plantar flexion exercises (ankle exercise) were introduced to perform motivative exercise for lower extremities.

We investigated the actual condition of motivative exercise for 30 inpatients within the facilities by using the developed evaluation device above outlined and developed the AU patent ³. Then we investigated which parameters have a correlation for the walk ability during the knee and ankle exercises by comparing the results of exercise elements through the implementation of the knee and ankle exercises and the analysis of the subject's walk condition.

An average period, mean amplitude and average speed of exercise for the knee exercise and an average period, mean amplitude and average angular speed for the ankle exercise were defined as the parameters to assess.

We examined which parameter had the best correlation related to both the result and analysis of basic research in order to enable automatic measurement of walking ability from evaluation of the motivative exercise in the future due to extracting the specific parameter. Moreover, we enforced the evaluation of electromyogram and the infrared photography at the same time ⁴.

2. Development and Method
2.1. Device developed
For the elucidation of the mechanism of motivative exercise, the device which measures the range, an angle and/or speeds of the ankle and knee exercise and also collects the thermal image by a thermography automatically that was developed based on the patent. An outline of the apparatus is shown in Fig.1. The foot plate (275mm in length, and 250mm in width) was attached on the two parallel slide rails to the base plate. It enables values of movement to evaluate the knee exercise by making it go and come back on the rails. The mechanism of it was previously stated ⁵.

By this development, displacements of the cross direction of order were detected by the E6A2-
CS3E 200 P/R 0.5M, OMRON Corp made and measurable region was 565mm in the direction of order.
Displacements of rocking angles of a foot plate were detected by E6A2-CS3E 200 P/R 0.5M,
OMRON Corp made. The constant of the used spring was 0.52N / mm approximately. The software
for generating data was created by Microsoft "Visual Studio NET PRO MSDN DX 7.0J."

This development made the ankle dorsiflexion and plantar flexion exercises by stepping upon the
foot plate attaching the heel part to the sliding rails as a pivot axis enabling progress to be evaluated.
A coil spring was attached between the foot plate and base plate for giving load to the ankle during
exercise. The measurement systems shown in Figs. 2A and 2B were built and two personal computers
were used in order to obtain sampling through the exercise data, the electromyogram data, and infrared
picture photography. Data collection of this research was performed in Fig. 2A. In addition, the EMG
measuring device was made by DKH, Inc and an infrared camera was NIKON made.

2.2. Method
2.2.1. Measurement

The experiment was carried out using the
developed device, in which both feet were arranged and
placed on the foot plate while in a sitting position as
shown in Fig. 2C. Then displacement of the feet by the
knee motivative exercise shown in Fig. 2C(a) and ankle
motivative exercise shown in Fig. 2C(b) were obtained
and evaluated by the device. Figure 3 shows the
experiment in progress. At the time of the knee
exercise measurement, the position where an
articulation-genus angle becomes right-angled was
used as the initial position.

The displacement of forward movement was
made plus value and the displacement of backward
movement was made minus value rather than a value
while in the sitting position. In the case of the ankle
exercise, we settled on the initial position which
stepped into the maximum and measured time series
change of the direction displacement in order to have
feet rocking as the heels point and pivot. Figure 2 also
shows how to take the coordinates of each exercise simultaneously. The subject did not receive any
direct directions about the speed or the range of each exercise and exercised at the speed and the
number of times usually performed with directions from a physiotherapist. We performed
measurements on each exercise 30 times at a stationary state.
2.3. Parameters

By the development of the device stated, data collection about the evaluation parameter became possible for evaluating the feature of exercise, therefore the experiment of Motivative Exercise shown in Figs. 2C(a), (b) was performed.

(a) Knee flexion and extension exercises

The period and amplitude were defined as shown in Fig. 4A. Those average values were turned into the period and amplitude of the subject. The average speed of exercise was computed from the period and amplitude calculated.

(b) Ankle dorsiflexion and plantar flexion exercises

A period and amplitude were defined as shown in Fig. 4B. Average angular velocity was computed on the basis of rocking the foot plate terminal area as a pivot. In addition, the maximum dorsiflexion angle was restricted to 37 degrees by the device. Researched parameters were summarized in Table 1; this development enabled those measurements.

2.4. Walk ability assessment

Disabled elderly were divided into four groups: Free Walk(FW), Walk with Crutch(WC), Walker Walk(WW), and Walk in Parallel Bars(WP), according to training at the time of rehabilitation. This classification was defined from the evaluation technique of the physiotherapist who was enforcing the method. The physiotherapist's evaluation technique: uniqueness, a crutch walking, a walker walk, and the training walk in parallel bars. Furthermore, the youth-healthy person (Youth) was added, and as shown in Tables 2A and 2B, divided into five groups. Furthermore, the youth-healthy person's data was added as a candidate for comparison. The number of subjects of each group was shown in Tables 2A and 2B.

3. Subjects

This experiment was conducted for the 30 disabled elderly at the Geriatric Health Facilities for Elderly People or the health care facility for the elderly in Yokohama-city, Chigasaki-city and Fujisawa-city in Japan from July 9 to November 13, 2005. The subjects whose consent of the experiment was obtained were 25 women and 5 men. The average age was 82.3 years old, the oldest was 94 and the youngest was 62 years old. The subjects had two or more diseases: 9 with a sequela of
cerebral infarction, 8 with hypertension, 6 with a sequela of femur neck fracture, 4 with osteoporosis, 3 with osteoporosis, lumbar compression fracture and 9 with heart disease. The subjects with paralysis are shown in Table 3. The subjects living with a wheelchair were shown (LW).

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Walk ability in Daily Living</th>
<th>Walk ability in Rehabilitation training</th>
<th>Paralysis Side</th>
<th>reciprocate motion</th>
<th>Dorsiflexion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65</td>
<td>FW</td>
<td>FW</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>69</td>
<td>WC</td>
<td>FW</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>83</td>
<td>WC</td>
<td>WC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>WC</td>
<td>WC</td>
<td>R</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>WC</td>
<td>WC</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>73</td>
<td>WC</td>
<td>WC</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>76</td>
<td>WC</td>
<td>WC</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>80</td>
<td>WC</td>
<td>WC</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>84</td>
<td>WC</td>
<td>WC</td>
<td>R</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>77</td>
<td>LW</td>
<td>WC</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>84</td>
<td>LW</td>
<td>WC</td>
<td>R</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>84</td>
<td>LW</td>
<td>WW</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>13</td>
<td>92</td>
<td>WW</td>
<td>WW</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>14</td>
<td>92</td>
<td>LW</td>
<td>WW</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>15</td>
<td>89</td>
<td>LW</td>
<td>WW</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>16</td>
<td>90</td>
<td>LW</td>
<td>WW</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>17</td>
<td>81</td>
<td>LW</td>
<td>WW</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>18</td>
<td>74</td>
<td>LW</td>
<td>WP</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>86</td>
<td>LW</td>
<td>WP</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>20</td>
<td>88</td>
<td>LW</td>
<td>WP</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>72</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>78</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>23</td>
<td>94</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>24</td>
<td>89</td>
<td>LW</td>
<td>WP</td>
<td>R</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>87</td>
<td>LW</td>
<td>WP</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>26</td>
<td>91</td>
<td>LW</td>
<td>WP</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>27</td>
<td>89</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>28</td>
<td>86</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>29</td>
<td>78</td>
<td>LW</td>
<td>WP</td>
<td>L</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUM</td>
<td>30</td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AV</td>
<td>82</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Result
4.1. Knee flexion and extension exercises
Related to the subject of each group shown in Table 2A, the collected data of an average period, mean amplitude and the average speed of exercise shown in Fig. 4A were measured and shown in Figs. 5A, 5B and 5C.

i. Period
The average time of 1 round-trip for knee exercise is expressed. The average period of every group is about two seconds, and a tendency special between a period and walk ability and any feature for every group cannot be read in Fig. 5A.
ii. Amplitude

The average value of the sum of the displacement reciprocating movement ahead and the displacement reduced to back is expressed of cross direction. A subject with this larger value has a larger movable region. The tendency for amplitude to be large can be read from Fig. 5B as the high subject of walk ability.

iii. Speed

It is the speed of the knee exercise and is evaluating using the average value of the value for every period. Figure 5C shows the tendency that subjects of high walking ability were shown high average speed.

4.2. Ankle dorsiflexion and plantar flexion exercises

Related to the subject of each group shown Table 2B, the collected data of an average period, an average angle, and the average angular velocity of exercise about the exercise shown in Fig. 4B were measured and were shown in Figs. 5D, 5E and 5F.

i. Period

The average time of one round rocking movement for ankles dorsiflexion and plantar flexion exercises is expressed. Tendency special between a period and walk ability and any feature for every group cannot be read in Fig. 5D.

ii. Angle

Angle means whether the ankle moved in the average angle which feet make to the level surface. Because the more the pliability of an ankle is large, the more the angle of ankles dorsiflexion and plantar flexion enable large, it can be said that the more this value is large, the pliability of ankles are large. The tendency for a movable angle to be large can be read from Fig. 5E as the high subject of walk ability.

iii. Angular velocity

Angle velocity is evaluating using the average value for every round trip of the feet centering on ankles. The tendency for an angular velocity to be large can be read from Fig. 5F as the high subject of walk ability.
4.3. Preparation of the parameter extraction

The average value and average value of the standard deviation between all the subjects of the parameter for evaluation of each exercise were computed and collected into Tables 4A and 4B except for the abnormal value. The average value of the standard deviation was computed by the following formula; the standard deviation for every individual was computed.

\[
\sigma_{sub} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (X_{subi} - \bar{X}_{sub})^2}
\]

N: Number of cycle

The average of the value of all the subjects' standard deviation was computed.

\[
\bar{\sigma} = \frac{1}{M} \sum\sigma_{sub}
\]

M: Number of subject

<table>
<thead>
<tr>
<th>Table 4A. parameter extraction of knee flexion and extension exercises</th>
<th>Table 4B. parameter extraction of ankle dorsiflexion and plantar flexion exercises</th>
</tr>
</thead>
<tbody>
<tr>
<td>average value ((\bar{X}))</td>
<td>Period</td>
</tr>
<tr>
<td>average value ((\bar{X}))</td>
<td>1.8</td>
</tr>
<tr>
<td>average standard deviation ((\bar{\sigma}))</td>
<td>0.57</td>
</tr>
<tr>
<td>average value ((\bar{X}))</td>
<td>0.882</td>
</tr>
<tr>
<td>average standard deviation ((\bar{\sigma}))</td>
<td>0.284</td>
</tr>
</tbody>
</table>

4.4. Correlation coefficient and evaluation by multiple linear regression analysis

i. Correlation coefficient

Making into the purpose variable the group according to walk ability defined by the clause of “Walk ability assessment,” all the intervals assumed that it was equal. Marks were given to the group and it was determined as (Youth) = 5 point, (FW) = 4 point, (WC) = 3 point, (WW) = 2 point, and (WP) = 1 point. The correlation coefficient to purpose variable six parameters; \(y = 5,4,\ldots,1\) was computed and is shown in Table 5A. The subjects (Subject 4, 10, 12, 17, 20, 21, 25 and 28) with unique situations, such as dementia subject, were removed.

ii. Evaluation by multiple linear regression analysis

Since a correlation coefficient is high, regression using speed and an angle were computed.

\[
y = a_1 \times x_1 + a_2 \times x_2 + a_0
\]

\[
= 0.00387 \times x_1 + 0.0970 \times x_2 - 0.200
\]

\(a_1, a_2: \) Partial regression coefficient \(a_0: \) Intercept
\(x_1: \) Speed (Average) \(x_2: \) Angle (Average)

The value of F distribution in significance level \(\alpha = 0.01\) is; \(F_0 = F(p, n-p-1, \alpha) = F(2, 22, 0.01) = 5.719\)

The obtained variance ratio is compared with the size of F0. 17.982>F0;

The coefficient of determination is significant. Obtained regression expression;

\[
y = 0.00387 \times x_1 + 0.0970 \times x_2 - 0.200
\]

\(x_1: \) Speed (Average) \(x_2: \) Angle (Average)

However, the unit of an angle is \([\text{deg}]\) and the unit of speed is \([\text{mm/sec}]\), a meaning is not made even if it compares the value of a coefficient directly. In order to investigate which parameter has affected it more, the unit of data is arranged and uses a standard by the following formulas. In order to investigate
which parameter has affected it more, the unit of data is arranged and uses a standard by the following formulas.

\[
a_1' = a_1 \times \sqrt{\frac{S_{11}}{S_{yy}}} \\
S_{yy}, S_{11}, S_{22}: \text{Sum of squared deviation}
\]

\[
a_2' = a_2 \times \sqrt{\frac{S_{22}}{S_{yy}}}
\]

\[
a_1', a_2': \text{Partial regression coefficient}
\]

<table>
<thead>
<tr>
<th>Table 5A. Correlation coefficient</th>
<th>Table 5B. Covariance table</th>
</tr>
</thead>
<tbody>
<tr>
<td>knee exercises</td>
<td></td>
</tr>
<tr>
<td>Ankle exercises</td>
<td></td>
</tr>
</tbody>
</table>
| Period                            | # -0.10 Period             | y Speed angle
| Amplitude                         | # 0.67 Angle               | y 1.77 Speed 117 16691
| Speed                             | # 0.68 Angular velocity    | 117 0.0970 0.5001.77 47.00.0970 0.5001.77
| Table 5B. Covariance table        |                            |

The deviation square sum is read from a covariance table. A covariance table is shown in Table 5B.

Therefore, a standard partial regression coefficient is show below, and then walk ability is depended on an angle rather than a speed.

\[
a_1' = 0.00387 \times \sqrt{\frac{16691}{1.77}} = 0.376
\]

\[
a_2' = 0.0970 \times \sqrt{\frac{47.0}{1.77}} = 0.500
\]

5. Conclusion
Measurement apparatus were developed in order to extract the high correlation parameter of an advanced age subject's walking ability. As a result of having analyzed the exercise data acquired from the developed device, the following points became clear.

i. Knee flexion and extension exercises
The average value of amplitude and average speed suited the larger tendency as the subject who was doing the high level walking-training. Moreover, about the variation within a period, the subject of higher walking ability suited the small tendency.

ii. Ankle dorsiflexion and plantar flexion exercises
An angle and angular velocity suited the large tendency as the subject who was training the high level walking-training. Therefore it can predict that the subject of higher walk ability has the higher pliability of ankles. Moreover, with the variation in angular velocity, the subject of higher walking ability suited the small tendency.

iii. Multiple linear regression analysis
The place which assumed the subject's ambulatory ability to be 5-1 point, and conducted multiple linear regression analysis, then the regression which makes average speed and an angle an explaining variable was obtained. The angle was shown as a most effective index due to asking for a standardized partial regression coefficient and evaluating it.

iv. Observation
Progress of molecular genetics has brought about progress of incurable disease medical treatment. The elderly who are disabled by cerebrovascular disorder and/or functional disturbance do not improve, though rehabilitation medicine is received. They become bedridden, turn into a person requiring constant care, and are suffering. The Proprioceptive Neuromuscular Facilitation (PNF) to hemiplegic patients on the affected side priority must be reconsidered due to a lack of effect in its procedure. By the improvement of the theory and techniques of PNF, the improvement of therapeutic effects on the hemiplegia could be expected in connection with the progress. However the outcome of
medical examination has hardly been changed on hemiplegia patients at the clinical aspect compared with the results of 40 years ago. The rehabilitation by the TAKIZAWA method with the motivative exercise using the devices for the knee flexion and extension exercises and for the ankle dorsiflexion and plantar flexion exercises which is introduced in some welfare institutions for the aged and hospitals is evaluated as being significantly effective through the researches by the Japanese government grants and randomized control test. This research is the elucidation of mechanism of the knee and ankles’ motivative exercise as the foundation for reacquiring walking. The direction of future research became settled through this research. We will accumulate and analyze data from now on, and continue our effort so that automatic diagnosis of walk acquisition may be enabled.

It is expected to judge the walking ability automatically with using the device developed in the future by the study of a larger cohort of subjects. We will aim at getting government grants through competition from now on so that these researches on the motivative exercise of the lower extremities can be enabled. The pile of such research verifies the validity of methodized rehabilitation medicine. That would enable evidenced-based elucidation and the innovation of the cure through rehabilitation medicine and the methods of medical treatment to the after effect of cerebrovascular disease.

Acknowledgement
This work has been supported by the Grant-in-Aid for Scientific Research(C) 18560245. The Geriatric Health Facilities for Elderly People of Shonan no Oka and Skai, the health care facility for the elderly Azaria Home, Basyouen, and Fujisawa, and the physiotherapist Kyoko Takizawa. We are grateful for their support.

References
3) TAKIZAWA, Shigeo, Takizawa K: Lower limb function training device, AU Patent 2004201136, 2006
5) Yohei Nomoto, TAKIZAWA, Shigeo, Et al. Analysis of an electromyogram and the movable range for the Motivative exercise, Biophilia Rehabilitation Journal 2-1, pp48-50 2004
7) TAKIZAWA, Shigeo, AN APPLICATION OF THE CIVIL TECHNOLOGY TO THE SUSTAINABLE AGED SOCIETY, Biophilia Rehabilitation Journal, 2-1, p1-24, 2004
9) TAKIZAWA, Shigeo, Keeping the Elderly in Motion, Reha. Management international, Los Angeles, Medical World Communications, 48, 2000
10) Mitsuyo Makita, Nakadaira H, Yamamoto M: Randomized Controlled Traial to Evaluate Effectivenss of Exercise Therapy (Takizawa Program) for Frail Elderly, Environmental Health and Preventive Medicine 11, 5: 221-227, Sep. 2006