

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

185,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Haptic Device System for Upper Limb and Cognitive Rehabilitation – Application for Development Disorder Children

Yoshiyuki Takahashi¹ et al.*
*Toyo University, Tokyo,
Japan*

1. Introduction

A rehabilitation system using mechatronics, virtual reality can provide interactive therapy that engages the user's interest. It can also offer a simple and flexible environmental setup with precise recursive training and can gather training data at the same time. Several kinds of virtual reality applications are currently available in this field. For example, MIT-MANUS, MIME (Mirror Image Movement Enabler), Assisted Rehabilitation and Measurement (ARM) Guide, and a rehabilitation training system using an electrorheological actuator. Current research is primarily focused on providing effective rehabilitation of adult users. However, users of rehabilitation systems also include children. According to occupational therapists, therapy for developmentally disabled children should include a variety of training and typically requires hand-eye coordination because this is an important skill for school.

Currently, most conventional rehabilitation programs tend to be repetitive. Therefore, children are difficult for users to stay motivated while improving impaired functions. Nevertheless, several methods are available to evaluate the level of disability. These assessments are largely based on the therapist's subjective observations. Moreover, sometimes the result depends on the quality of therapy and the experience of the therapist. Therefore, it is necessary to measure, analyze, and evaluate the user's performance in objective and quantitative terms.

To solve these problems and meet specific requirements, we developed a rehabilitation system using a haptic device that integrates both motion and sensory therapy. The system is designed to maintain the user's interest during the rehabilitation activity. To evaluate the

* Yuko Ito², Kaoru Inoue², Yumi Ikeda², Tasuku Miyoshi³, Takafumi Terada⁴, Ho kyoo Lee⁵, and Takashi Komeda⁶

² Tokyo Metropolitan University, Japan

³ Iwate University, Japan

⁴ Mitsubishi Precision Co., Ltd., Japan

⁵ Hyogo Institute of Assistive Technology, Japan

⁶ Shibaura Institute of Technology, Japan

system and gather basic data for quantitative evaluation of the levels of disorders, we carried out experiments with healthy child subjects.

In this paper, an outline of our developed haptic device system is introduced and experiments on the interactions of kindergarten children with this system are described. It was found that the proposed system effectively performed hand-eye coordination training.

2. Research background

For children with a development disorder, occupational therapy is usually performed. Occupational therapy for such children includes a variety of different therapies with many evaluation methods either proposed or existing. A suitable therapy provides individual therapy to treat the level of the disorder and the age of the child.

In the therapy for young children, the goal is to prepare them for elementary school. Of course, preparation requires many different actions. Occupational therapy is mainly focused on obtaining handwriting skills and self-reliance in daily life. Thus, the goals of therapy are enabling development of dexterous hand and visual perception. This means that hand-eye coordination is important.

In occupational therapy, many different tools are used, for example, toys, musical instruments, paper projects, mazes, and puzzles. Most of these tools are readily available in retail markets. Also, some are handmade by the therapist. These tools are used not only for therapy but also for evaluation the level of disorder. However, the evaluation of the effects are mostly based on the therapist's subjective observations and conventional pen-paper tests. At the present time, evidence-based occupational therapy is desirable. Therefore, establishment of quantitative evaluation methods are required. To meet this need, we apply computer technology and virtual reality to conventional therapy.

Additionally, therapists are interested in how to motivate patients and maintain the motivation for both children and adults. Virtual reality devices offering visual and sound experiences provide tactile and haptic sensations, which are interesting for patients, especially young patients. Therefore, we developed an effective haptic device system with training software that provides a haptic sensation on a hand grip held by the user. The sensation generated depends on the visual program.

3. Haptic device system

3.1 Hardware system

Our haptic device system is intended for upper-limb rehabilitation. Fig. 1 shows a photograph of the proposed haptic device system. The system consists of a haptic device, a display, and a computer. The haptic device consists of two servomotors with reduction gears, link rods, a hand grip, and a flat panel. The grip and servomotors are connected by link rods. Patients can move the grip on the surface of the flat panel and train their upper-limb movements in horizontal.

The haptic device and the computer are connected by a USB interface. The moving range is 400 mm in the lateral direction and 250 mm in the longitudinal direction. The servomotors can apply a maximum force of 30 N to the grip. Optical encoders are attached to the

servomotors. The position of the grip is calculated by the encoder pulse count and the length of the link rods. The LCD display shows the visual symbols of the training programs. The aspect ratio of the work field on the display is proportional to the actual flat panel. Advantages of the haptic device are ease of handling and portability in a hospital or a home. In this model, the user only needs to plug in the USB connector to a PC and run the training program. The computer executes the following functions:

- Controlling the haptic device
- Displaying the training program
- Acquiring the training data
- Evaluating the training result



Fig. 1. Haptic device system

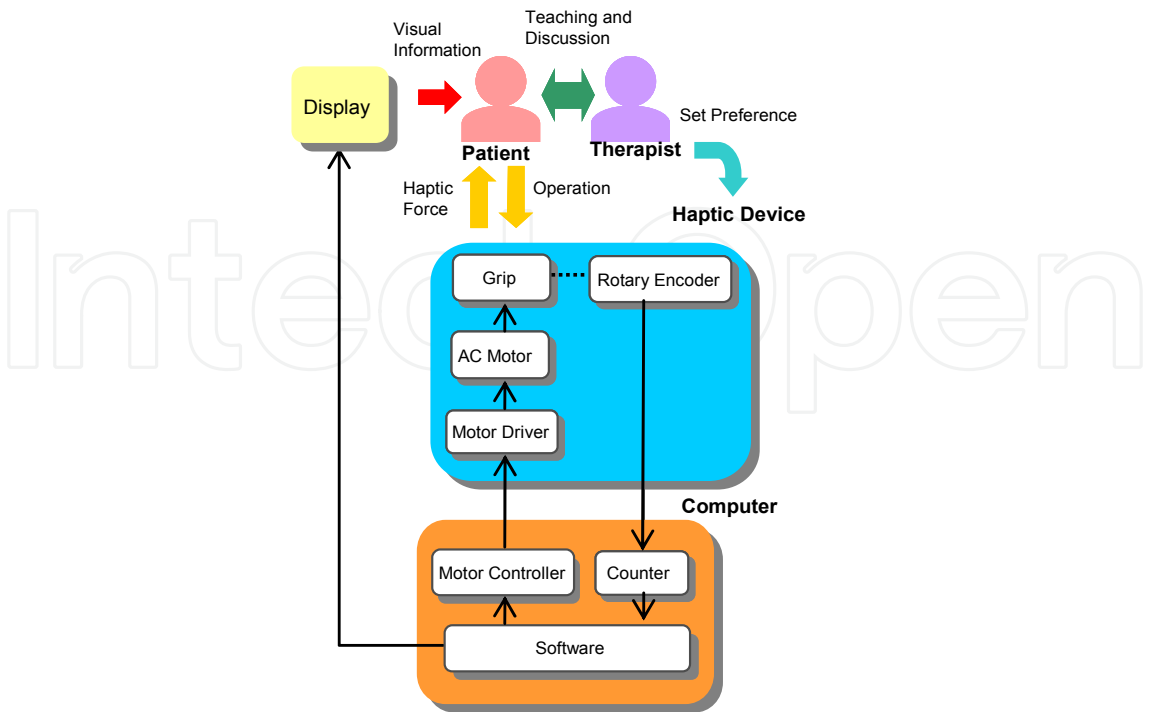


Fig. 2. Flow of the haptic device system

3.2 Haptic force generation

Six types of haptic forces can be provided on the rehabilitation system: load, assistance, spring, viscosity, friction, and special effects. The therapist can change the type and magnitude of the haptic force according to the user's level of disorder. The details of each force are described as follows.

1. **Load:** The load force is generated in the opposite direction of the grip velocity vector. The magnitude of the force increases in proportion to the distance between the current grip position and the target position. Load force F_l is shown in (1). When the grip position is (x, y) , the target position is (x_0, y_0) and the gain is K_l .

$$F_l = \begin{bmatrix} F_{lx} \\ F_{ly} \end{bmatrix} = K_l \left(\begin{bmatrix} x_0 \\ y_0 \end{bmatrix} - \begin{bmatrix} x \\ y \end{bmatrix} \right) \quad (1)$$

2. **Assistance:** The assistance force is generated in the same direction as the grip velocity vector. The magnitude of the force increases in proportion to the distance between the current grip position and the target position. The assistance force F_a is the same as the force in (1), except the gain is replaced by K_a .
3. **Spring:** The spring force is generated in the direction of the initial grip position. The magnitude of the force increases in proportion to the distance between the current position and the initial position of the grip. The spring force F_s is the same as the force in (1), except the gain is replaced by K_s .
4. **Viscosity:** The viscosity force is generated in the opposite direction of the grip velocity vector. The magnitude of the force increases in proportion to the velocity of the grip. The viscosity force F_v is shown in (2). The gain is K_v .

$$F_v = \begin{bmatrix} F_{vx} \\ F_{vy} \end{bmatrix} = K_v \begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} \quad (2)$$

5. **Friction:** The friction force is generated in the opposite direction of the grip velocity vector. The magnitude of the force is constant. The friction force F_f is given as shown in (3). The gain is K_f .

$$F_f = \begin{bmatrix} F_{fx} \\ F_{fy} \end{bmatrix} = K_f \begin{bmatrix} \frac{\dot{x}}{|\dot{x}|} \\ \frac{\dot{y}}{|\dot{y}|} \end{bmatrix} \quad (3)$$

6. **Special effect:** The special effect force F_e is generated especially in game programs (e.g., the contact force of the pieces of the puzzle and the reaction force when hitting some object).

Therefore, the total haptic force on grip F is the sum of the above six forces, as shown in (4).

$$F = F_l + F_a + F_s + F_v + F_f + F_e \quad (4)$$

A haptic force other than the above can be generated by easy modification of a program.

4. Software for rehabilitation and evaluation

The software has two functionalities: training and evaluation. The training program consists of six different programs. The evaluation program consists of four different programs. When moving the grip, the cursor on the display simultaneously moves with the grip, and the haptic device provides a force that can either assist the movement of the arm or work against it. The level and the direction of the force are also adjustable. Moreover, the user can sense haptic perceptions such as contact force, viscosity, and surface friction. The data acquisition program runs with both programs and stores training data such as the time and the grip position. This data can be used in the quantitative analysis for motor control as well as cognitive function rehabilitation. Fig. 3 shows the program selection menu. The four icons on the left side are evaluation programs and the six icons on the right side are training programs.

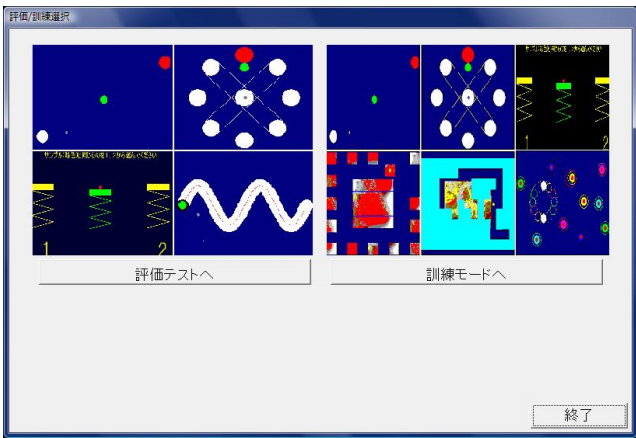


Fig. 3. Program selection menu

4.1 Training program

In the training programs, the user is urged to move her or his arms along diagonal, straight, and voluntary paths. The user can work a puzzle and play other game-like programs. These programs also help the user to develop concentration during training. Screenshots of the programs are shown in Figs. 4 to 7. Details of the programs are presented in the following.

1. Following the dot in the diagonal direction: White circles are positioned in the display in a diagonal position. A green target dot moves between two circles, and the user follows the target green dot by using the cursor. The color of the circles changes from white to red when the user attains the goal. The radius of the circles and the velocity of the target dot can be changed.
2. Following the dot in the radial direction: Nine circles and nine line sets, which connect the circle in the center, are shown on the display. The user tries to move the cursor from circle to circle while staying on the lines by following the target dot. The displacement and radius of the circles can be changed.
3. Feeling the haptic force: Three subprograms to feel the difference of haptic sensations are prepared (Fig. 4). The sensations are spring force, viscosity force, and load (weight). Three different objects appear on the display and each object provides a haptic force. The user tries to touch and move the virtual objects and feel the haptic forces. The right

- or left objects have the same magnitude and texture haptic force of the center object. The user tries to check which side object has same of center one. The subprograms, types and magnitude of the haptic forces can be selected from the pop-up menu.
4. Puzzle: The puzzle frame is shown in the center and the puzzle pieces are shown around the frame (Fig. 5). The user tries to pick and move each piece to the appropriate position in the frame and complete the puzzle to show the original image. When moving the the piece, the user can feel the weight of the piece. The original puzzle image can be generated from uploaded pictures. The user or therapist can select and use a favorite or suitable picture for training. The number and the weight of pieces can be changed to adjust the level of difficulty.

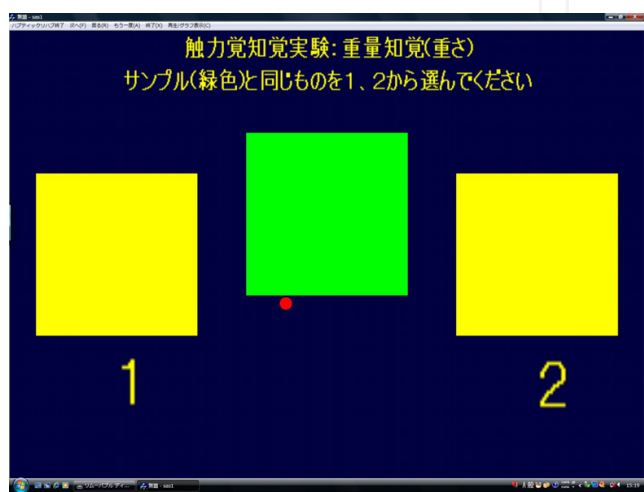


Fig. 4. Comparing the load (weight) of the objects

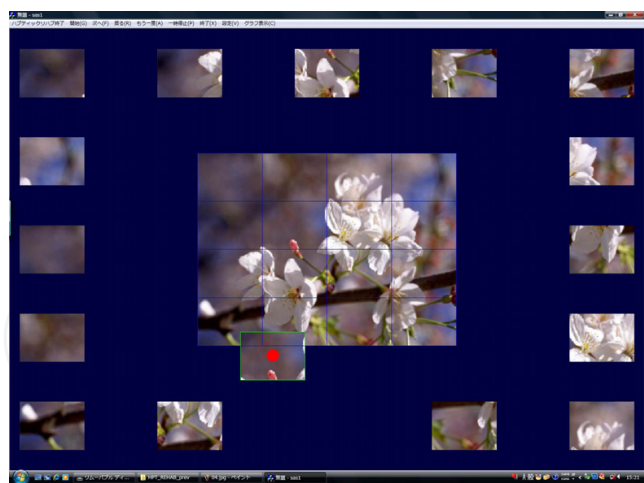


Fig. 5. Puzzle

5. Sweeping tiles: Square-shaped colored tiles are shown in the display (Fig. 6). The user tries to move the cursor over all of the tiles. When the cursor is located over a tile, the color of the tile is replaced with a hidden picture. Pictures interesting to the user can be displayed to keep his or her concentration during the training. Prepared arbitrary picture files can be used as the hidden pictures. The number of tiles and the magnitude and direction of the virtual force in the training are adjustable.

6. Balloon operation: Colorful circular rings are shown in the center of the display and ringed solid circles are randomly located around the rings (Fig. 7). The user tries to move the ringed solid circles to the same color rings at the center of the display. Each ringed circle has a different a virtual weight and vulnerability. When pushing the ringed solid circle by using the cursor, if the user pushes hard (by moving quickly), the ring and circle will be broken. The goal of this program is to move the all ringed circles to appropriate colors.

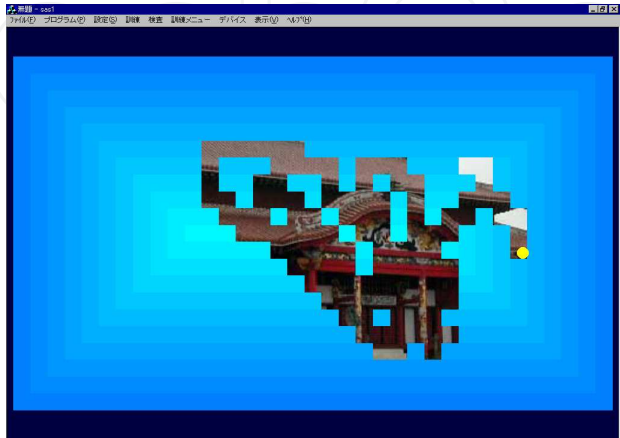


Fig. 6. Sweeping tiles

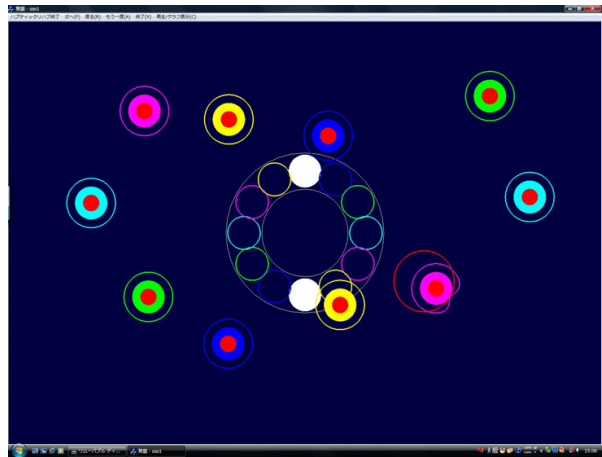


Fig. 7. Balloon operation

4.2 Evaluation program

The four evaluation programs can record time, grip position, velocity, error of the grip position, and so on. The contents of the programs are almost the same as those of the training programs.

One of the evaluation programs, “Wave”, is described in this section. Two circles and a sine-wave-shaped line are shown in the display (Fig. 8). The circles are connected with a wavy line. The user tries to move the cursor from one circle to the other while staying on the line. The amplitude and the cycle of the wave can be changed.

In addition, game-like evaluation programs for the children to use are also prepared. The details are introduced in the next section.

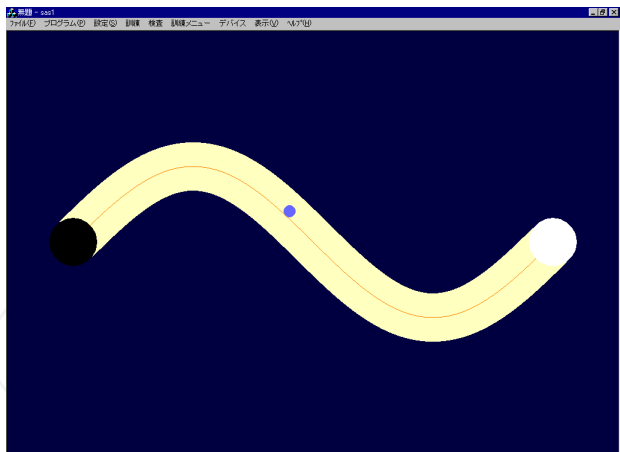


Fig. 8. “Wave” program for evaluation

5. Materials and methods

The haptic device system, consisting of the haptic device and rehabilitation software, was designed for functional and cognitive rehabilitation. The system was tested in experiments to apply and evaluate the haptic system as therapy.

5.1 Subjects

Twenty-seven subjects from the same kindergarten initially participated in this experiment. The age of the subjects ranged from 4 years 7 months to 6 years 3 months, and the average was 5 years 5 months. All subjects were right handed and one subject wore glasses. Of these 27 subjects, the experimental data of only 20 subjects (8 males and 12 females) were used, as explained below.

Informed consent was obtained from all parents of the test subjects and from the kindergarten staff. The experiment was approved by the Research Ethics Committee of Tokyo Metropolitan University.

5.2 Tasks and protocols

The experiment was carried out in the playroom of the kindergarten that the children attended. Test subjects were positioned in a chair (seat height: 290 mm, back height: 510 mm) in front of a desk (height: 470 mm, width: 1200 mm, length: 750 mm) that they regularly used. The haptic device and the display were placed on the desk, as shown in Fig. 9.

The test subjects were asked to play the evaluation program. The goal of this program, called “Starfish”, was to move the starfish from the right end to the left end of the display along the thick blue curve with a red centerline as quickly and precisely as they could. This program is a variation of the “Wave” program mentioned in the previous section. The display image is shown in Fig. 10. The experimenter asked the subject to bring the starfish back home quickly because a big fish is after it. Also, the user pays attention to sea urchins along the edge of the thick curve. The sea urchins can prick the starfish with their needles. In the experiment, the subjects tried three different haptic force settings. One is viscosity force, which is related to the velocity of the grip motion. The other one is assistance force, which

guides the cursor to the target position. The last one is no force is applied. The experiments included another two different trial programs before the “Starfish” program. A total of 10 minutes was spent for each subject. After playing the experimental game, an interview was carried out.



Fig. 9. Subject in the experiment

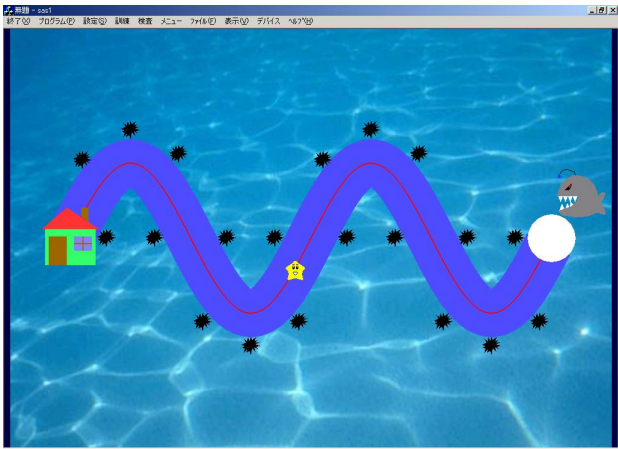


Fig. 10. “Starfish” program used in the experiment

6. Results

6.1 Comparison of time and error

The experimental data of four subjects could not be used due to the subjects’ misunderstanding of tasks and some mistakes in the system setting. The data of another three subjects were statistically eliminated. Of these three, two subjects moved the grip too quickly and had large errors, and another subject moved the grip too slowly and took a long time to play the game. Thus, the data of a total of 20 subjects were compared for duration time, grip (cursor) position error from the center of the wave line, and subject age.

Fig. 11 shows the relationship between the duration time and age with the three variations of applied haptic force. The horizontal axis is expressed as the log of the age. No significant correlations are confirmed. For example, the highest correlation, $R^2 = 0.0029$, is in the case of “no force applied”.

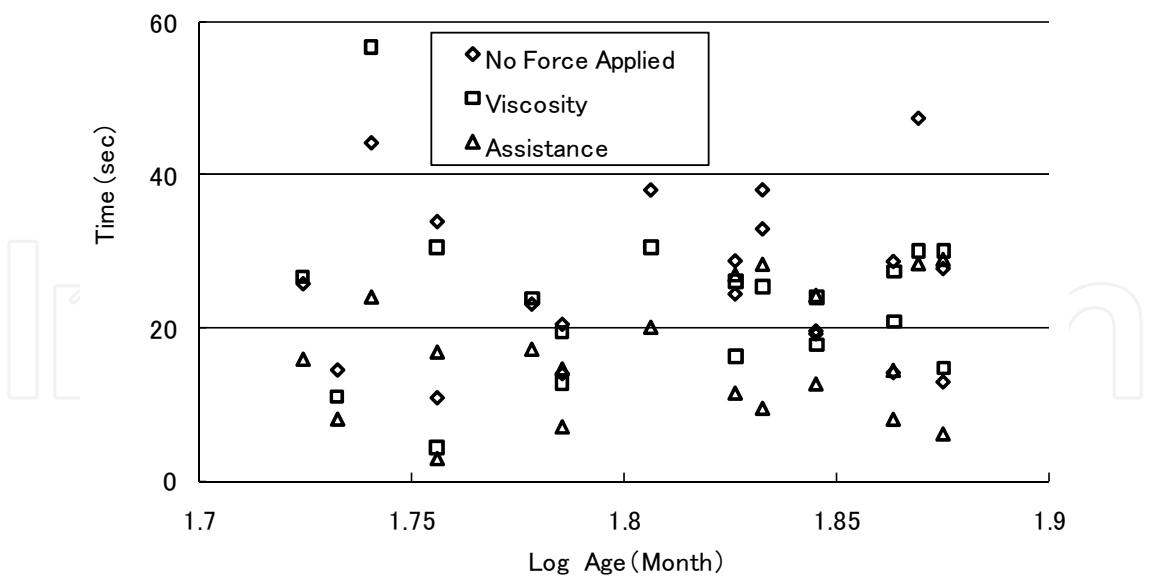


Fig. 11. Relationship of age of subjects and duration time

Fig. 12 shows the relationship between the root mean square (RMS) error of the grip position and the age with the same three variations of applied haptic force. The horizontal axis is again expressed as the log of the age. The correlations are negative in all cases. The RMS errors of the older subjects are lower than those of the younger subjects. The highest correlation, $R^2 = 0.330$, is confirmed in the case of “no force applied”. In the case of “viscosity”, the correlation is $R^2 = 0.256$. The case of “assistance force” has the lowest correlation, $R^2 = 0.102$.

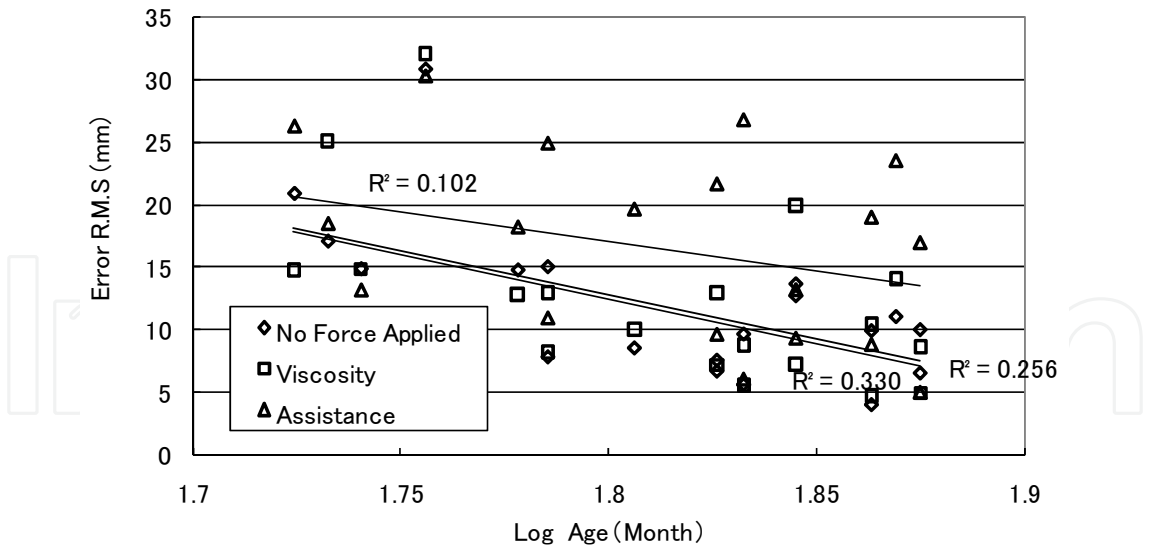


Fig. 12. Relationship of age of subjects and RMS error of the grip position

Fig. 13 shows the relaxation between the duration time and RMS error of the grip position with the three variations of applied haptic force. The horizontal axis is represented as the log of the duration time. All correlations are negative. This tendency is the same as that confirmed in a previous experiment by adult subjects. The correlation for “viscosity” is $R^2 = 0.464$, that for “assistance force” is $R^2 = 0.400$, and that for “no force applied” is $R^2 = 0.239$. The slope of the

regression line of “viscosity” is steeper than those of the other two cases. This result means that the viscosity force assists the precise grip position control. In contrast, the assistance force assists the grip movement toward the designated position, which allowed the user to move the grip quickly. However, a short duration time generally incurs a large position error.

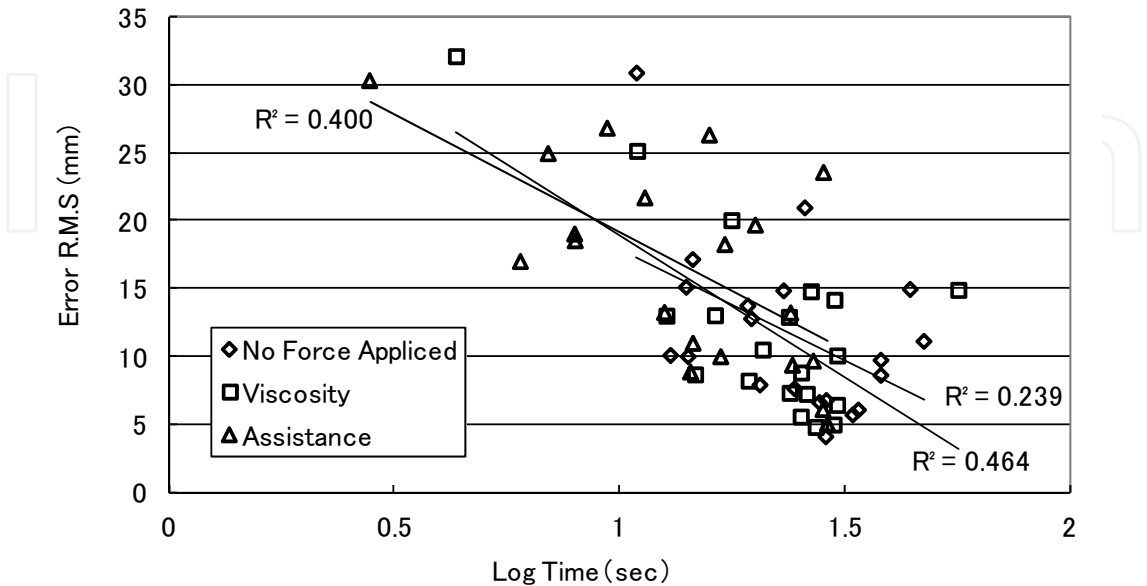


Fig. 13. Relationship of duration time and RMS error of the grip position

		Time	
		increased	decreased
RMS error	increased	1	11
	decreased	6	2

(a) Viscosity

		Time	
		increased	decreased
RMS error	increased	0	15
	decreased	2	3

(b) Assistance

Table 1. Number of subjects showing a difference in duration time and RMS error of the grip motion for “no force applied” and one other force. (a): “No Force Applied” and “Viscosity”, and (b): “No Force Applied” and “Assistance”.

Table 1 shows the number of subjects showing a difference in duration time and RMS error for “no force applied” and another force. The experiments were always done in the same order. Thus, if the training affected the results, the subjects would move the grip more quickly (duration time decreases) and more precisely (RMS error decreases) for “no force applied”. Table 1 (a) indicates the case of “viscosity”. The RMS error increased and the duration time decreased for 11 subjects (55%). In the case of “assistance”, shown in Table 1 (b), the RMS error increased and the duration time decreased for 15 subjects (75%). Conversely, in (a) the duration time increased for 7 subjects (35%) in the case of “viscosity” and in (b) for 2 subjects (10%) in “assistance”. The RMS error decreased for none of the subjects. In other words, the relationship between the duration time and RMS error has the same tendency of the previous results, and so the training effect can be excluded from consideration.

The difference of duration time and the difference of RMS error of the grip position are plotted in Fig. 14. This figure confirms the high correlation of “assistance”. The average

duration time of “viscosity” is -2.31 sec and that of “assistance” is -9.76 sec. The average RMS error of “viscosity” is 0.38 mm and that of “assistance” is 4.89 mm. In both cases, the significant difference was confirmed by a T-test ($p<0.05$).

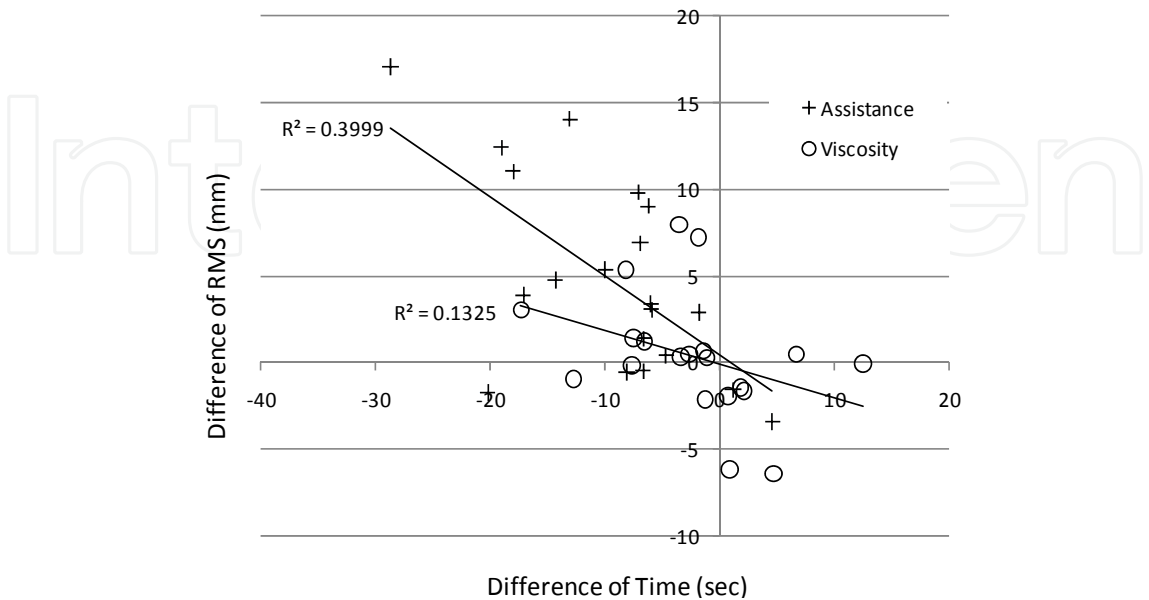


Fig. 14. Relationship between the difference of duration time and difference of RMS error of “viscosity” and “assistance”

6.2 Interview

A post-experiment interview was carried out for all subjects. 19 subjects answered the question “How was this game?” The subjects could answer freely about her or his impression of the experimental program. The vocabulary of their explanations was limited because they were young. The most common answers were “fun” (12 subjects), “interesting” (9 subjects), and “easy” (3 subjects). All subjects who gave an answer had a positive impression.

Two subjects gave both positive and negative impressions. Subject A (age 4 years 9 months, male) said, “Fun, but one of the pre-experiment programs was not interesting. It was too easy.” Another subject B (age 5 years 8 months, male) said, “Fun, but I was tired.” Subject A moved the grip quickly and finished tasks more quickly than average. In contrast, subject B moved slower than average and had less error than average. However, in the case of “assistance”, subject B moved quickly and the error increased. This could be a sign of fatigue (Table 2).

Simple questionnaires were also used. We asked two questions: “Are you good at sports?” and “Are you good at TV games?” The subjects were categorized into a “good at” group and a “not good at” group. Table 3 shows the comparison of the group results and the average results. There are no significant differences. However, the “Good at Sports” and the “Good at TV Games” groups tend to have a shorter duration time than that of the “Not Good at Sports” or “Not Good at TV Games” groups. Due to the shorter duration time, the RMS error of the “Good at” group is larger than that of the “Not Good at” group. The “Good at Sports” group and the “Not Good at Sports” group can generally be expressed as “active” or “non-active” personality groups. The tendency of their motions may be quick, however the results are a shorter duration time and a larger RMS error. The “Good at TV

Games” group may be more familiar with computers and playing TV games. Therefore, they do not operate the grip and program carefully.

	No Force Applied		Viscosity		Assistance	
	duration time	RMS error	duration time	RMS error	duration time	RMS error
Subject A	10.93	30.83	4.35	32.04	2.79	30.27
Subject B	38.11	9.7	25.39	8.76	9.4	26.77
Average	26.01	11.71	23.7	12.08	16.25	16.6

Table 2. Comparison of results between subjects with negative impressions and the average

	No Force Applied		Viscosity		Assistance	
	duration time	RMS error	duration time	RMS error	duration time	RMS error
Good at Sports	23.47	14.11	23.37	13.63	11.8	18.51
Not Good at Sports	30.28	9.82	14.34	12.45	19.28	16.86
Good at TV Game	24.08	12.15	22.18	12.36	15	16.43
Not Good at TV Game	29	11.03	25.97	11.66	18.11	16.84
Average	26.01	11.71	23.7	12.08	16.25	16.6

Table 3. Comparison of results between “Good at Sports”, “Not Good at Sports”, “Good at TV Games”, and “Not Good at TV Games” groups and the average

7. Discussion

No correlation was found between the age and the duration time. The assumed reason is the range and the variation of the subjects’ ages. Some younger subjects could not clearly understand the instruction, “Keep cursor (starfish) inside the thick wavy line” and operated it impulsively. Some older subjects understood the purpose of the program, “Try to keep moving the cursor on the center of the thick wavy line” and tried to do it carefully. Therefore, when the subjects are younger or they are not developing as expected, the experimenter should explain the task using easy words and be careful to make sure the subjects understand.

In the comparison between “no force applied” and “viscosity” or “assistance” applied, the duration time with the “assistance” force was shorter than that of the other cases. In the “assistance” case, it was observed that the upper limb of the subjects seemed to be pulled by the haptic device. Thus, the “assistance” force may prevent voluntary motion. However, for children who have problems with voluntary upper-limb movement or hand-eye coordination, the guiding force can help move her or his upper limb (grip) to the designated point. This assistance can stimulate motion and cognitive function. The suitable level of assistance and how it is involved in therapeutic training should be discussed in the future.

The error of motion decreased according to age. It was confirmed that error and age have a negative correlation. From observations, it was also confirmed that most of the older subjects tried to move the cursor along the center of the thick wavy line in the “Starfish” program. Thus, the results were reasonable. However, children at 5 years of age start to write Japanese characters and Arabic numbers as preparation for elementary school. Therefore, a simple line-drawing task should be easy for them to understand.

The negative correlation for the duration time and the grip position error was confirmed in the two different cases of applied force and no force applied. The tendency was the same as that in previous research for young adult to elderly subjects. To move the cursor in a smooth and fast manner, the subject must see the cursor, recognize its position, and move the

direction of the cursor by moving his or her upper limb to the appropriate position. Usually, this ability is obtained by visuomotor experience beginning at birth. Moreover, improved and refined actions increase with the increase of experiences. In many cases, developmental disorder children lack many skills. They have a problem with hand-eye coordination due to their learning difficulties and lack of sensory-motor experiences. From the viewpoint of occupational therapists, upper-limb motion depends on stability and control of the trunk and shoulder. Therefore, they focus on improving posture, stability, and shoulder control before using therapeutic tools. During operation of the haptic device system, the users held their trunk in median antigravity. The upper limb was held in the air, and the fingers were used to hold the grip. Shoulder and elbow joint motion were involved with the motion of the grip. Especially, moving one's hand on a smooth curving trajectory, as in the experimental programs, requires coordination of multiple functions, direction control by the shoulder joint, and position adjustment of the elbow joint. Thus, the haptic device system, which uses upper-limb motion with visuomotor involvement, can be effective for hand-eye coordination training.

8. Conclusions

We developed a rehabilitation system using a haptic device that integrates both motion and sensory therapy. The system is designed to maintain the user's interest during a rehabilitation activity and also to provide a quantitative evaluation for occupational therapists. From the results of experiments with kindergarten children, a negative correlation of duration time and motion error was confirmed in the two different cases of applied force and no force applied. In addition, the motion error decreased according to age. It was found that this developed system effectively motivated and evaluated hand-eye coordination.

9. Acknowledgment

I would like to acknowledge the generous support received from Dr. Takagi and the students of the Tokyo Metropolitan University and Shibaura Institute of Technology who assisted in the experiments conducted during this research.

10. References

- Krebs I. H, Hogan N, Aisen L. M, Volpe T. B. (1998). Robot-Aided Neurorehabilitation. *IEEE Transactions on Rehabilitation Engineering*, vol.6, No.1, pp. 75–627.
- Shor C. P, Lum S. P, Burgerk G. C, Van der Loos M. F. H, Majmundar M, Yap R. (2001). The Effect of Robotic-Aided Therapy on Upper Extremity Joint Passive Range of Motion and Pain, *Assistive Technology Research Series*, vol.9, pp.79–83.
- Kahn E. L, Averbuch M, Rymer Z. W, Reinkensmeyer J. D, Comparison of Robot-Assisted Reaching to Free Reaching in Promoting Recovery From Chronic Stroke. (2001), *Assistive Technology Research Series*, vol.9, pp.39–44.
- Furusho J, Koyanagi K, Ryu U, Inoue A, Oda K. (2003). Development of Rehabilitation Robot System with Functional Fluid Devices for Upper Limbs. *International Journal of HWRS*, vol.4, No.2, pp.23–27.
- Takahashi Y, Terada T, Inoue K, Ito Y, Lee H, and Takashi K. (2003). Upper-Limb Rehabilitation Exercises Using Haptic Device System. *International Journal of HWRS*, vol.4, No.2, pp.18–22.

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen