Original Article

# Differences in Manual Exercise Therapy Skills between Students and Therapists

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## Abstract

**Purpose**: We have developed a hemiparetic patient arm robot (Samothrace: SAMO) for repeated practicing of manual exercise therapy. In this study, and our aim is to quantify the differences in manual exercise therapy skills between students and therapists.

**Subjects and Methods**: The subjects consisted of one occupational therapist and three fourth-year university students. Examples of elbow joint exercises were displayed on a PC screen, and while observing the examples, the subjects passively flexed and extended the elbow joint of the arm robot, with the exercises being recorded by SAMO.

**Results and Conclusion**: When comparing the movement of the elbow joint of the robot, the maximum flexion angle of the robot arm was significantly smaller in the case of the students than the occupational therapist, and the maximum extension angle was larger for the students than the therapist. Further, the maximum angular velocity and maximum angular acceleration with which the students moved the elbow joint of the robot was significantly higher than those of the occupational therapist. The results obtained showed that the frequencies of articular movement by students were smaller than those in the examples and those of the therapist, and the cycle of joint angle changes was prolonged. In addition, the force applied to the robot arm by the students had a longer cycle than that in the examples. These results verified that, compared to the therapist, the students were not fully versed in the passive exercises corresponding to passive abnormal muscle tone in an elbow joint flexor group and an extensor group.

**Keywords:** Patient robot, hemiparetic spasticity, occupational therapist

## Introduction

An occupational therapist analyzes the cause and location of movement limitations in structures such as muscles, joints, and the soft tissue (Pedretti, 1996; Rybski, 2004). Mobility is restored through exercise therapy involving stretching or massaging of a patient's muscles, joints, ligaments, or skin. For example, when evaluating abnormal muscle tone in patients with motor paralysis, a therapist will slowly or rapidly move the muscles of the patient in accordance with the state of the soft tissue, and thereby detect passive muscle tone (Barnes, 2008). Then, continuous extension is used to improve articular movement in places presenting abnormal muscle tone (Oddeen,

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1984). Reportedly, 30 or 60 seconds of continuous extension performed five times weekly for six weeks is effective with adult patients ages 40 to 64 (Bandy, 1994), whereas 60 seconds of continuous extension performed five times weekly for six weeks is effective with elderly patients age 65 or older (Feland, 2001). Extension time, direction, and speed need to be regulated to provide the optimum extension for a patient's condition, as it will differ depending upon age, the cause of movement limitations, and the extension period (Cameron 2012). Novice therapists learn the necessary skills for this at rehabilitation training schools.

Students wanting to become therapists sometimes learn theories of manual exercise therapy from textbooks, and then study the necessary skills by viewing video teaching materials. For practical training, they take turns imitating patients with impaired movement and engage in simulated practice on each other. However, it is felt that many of the students who learn their skills in this manner are not fully capable of serving as therapists on their own, and therefore require further practice to truly develop the proper skills (Hodgetts, 2007). Sometimes Objective Structured Clinical Examinations (Harden, 1988) using mock patients are conducted so that instructors can verify that students have acquired practical skills. However, it is difficult for students to fully understand all aspects of patient pathology exercises, such as the stiffness of patient muscle and ligaments, through such skills training as they do not come into contact with actual patients.

Thus, in past skills education classes for manual exercise therapy, when students attempted to reproduce the procedures while watching it being performed by instructors, they did not know the amount of force they were applying on the patients and found it difficult to improve their own skills. In other words, the students remained unskilled in the understanding and practice of exercise therapy skills needed for pathology exercises.

In addition, instructors have no real means of assessing the articular movement performed by applying force to patient's bodies for manual exercise therapy. In past evaluations of manual exercise therapy skills, the patient's muscle tone decreased after exercise therapy, and determinations were made from the expanded joint range of motion and decreased viscoelasticity effects (Yeh, 2007; Hagbarth, 1985). However, with this evaluation method, although manual exercise therapy effects were assessed, factors related to skills, such as the joint angles during movement, movement velocity, and force applied on the patients in pathology exercises, could not be assessed objectively. In other words, instructors do not verify whether students have fully acquired manual exercise therapy skills. If it is difficult for training school instructors to ascertain the proficiency level of manual exercise therapy skills acquired by students, then there is a risk that students with inadequate skills will hamper therapeutic effects when treating actual patients. Hence, there is a need to measure at least the degree of skill possessed by students resulting from study in skills courses. In recent medical education, it has been proposed to identify the features of necessary skills, and then provide education based on individual student skill levels (outcome-based education) (Harden, 2002). Consequently, determination of whether students have fully acquired manual exercise therapy skills is important for evaluating their education.

Skill evaluation using patient robots may be effective in teaching exercise therapy. Patient robots are often used in simulation education in the medical field (Tanzawa, 2013; Takanobu, 2008). We developed an arm robot (development code Samothrace: SAMO, Patent number:

6307210) capable of reproducing patient pathology exercises and recording articular movements applied to it by a person. SAMO can record the articular movement applied by a person to a robot arm, wherein the recorded data are in the form of articular movement speed and force values, which can be compared with those of another person applying the same movement. When these are analyzed and compared against the recordings of experts, it may be possible to evaluate student skill proficiency levels. Therefore, this robot arm may be used in rehabilitation education for pedagogical purposes. In this study, by recording the manual exercise therapy of students and therapists using the developed Samothrace, we aim to quantify the differences in the exercise therapy skills.

## Subjects and Methods

### 1. Summary of the developed SAMO

SAMO has an arm structure section, an actuator section driving the arm, an application for controlling the actuator, and an application section for recording the external force received by the arm from a person's hand and for analyzing the acquired information (Figure 1). The arm structure has a right humerus, radius, and ulna vacuum-casted from aluminum alloy, and a hand part made of resin. The arm frame and actuator are driven by tightening wires. The wire used is an active core wire passed through a hollow sheath. The actuator uses a hybrid stepping motor with an encoder made by Vanguard System (ST-Servo System), and voltage values obtained from the actuator can be converted into joint angles, angular velocity, and force for recording. Articular movement reproduces elbow joint flexion and extension, forearm pronation and supination, and wrist flexion and extension. Skin and subcutaneous soft tissue covering the frame are made from resin mixed with silicon and polyurethane (Figure 2).

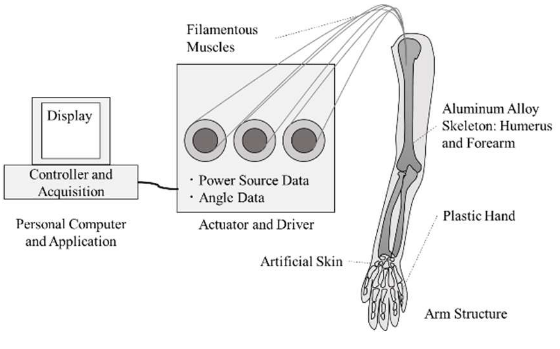
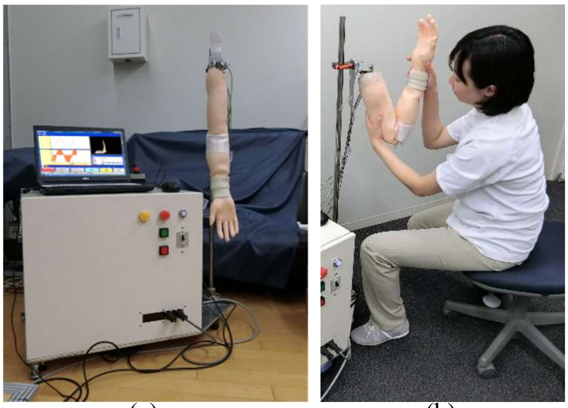


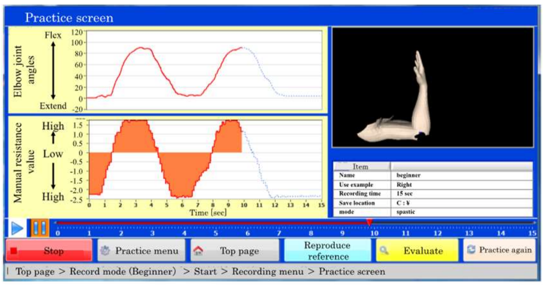
**Figure 1:** System summary of Samothrace (SAMO) Display shows robot joint angles and force on a monitor. Controller switches between spastic, rigid, and flaccid modes with Application. Acquisition converts motor voltage values into force. Angle Data: Converted from pulley angle of rotation. The Arm Robot frame is cast from aluminum alloy, and the hand part is made of resin. A spastic, rigid, and flaccid mode program drives actuator and pulleys joined with filamentous muscle. The outer skin of the frame is made of synthetic resin.



(a) (b)

**Figure 2:** Developed arm robot system (SAMO) (a) Frame, actuator, and driver tightened by wires housed in a box to the right of the arm robot. A controller and a data displaying PC are placed on top of the box. (b) Experimental setup with manual exercise therapy performed with SAMO reproducing exercise pathology.

Spasticity is one symptom that occurs with upper motor neuron disease, and involves enhanced stretch reflex (Nathan, 1973). With spasticity, resistance is weak during slow passive exercise, and strengthens with fast passive exercise (Barnes, 2008). On the other hand, stretch reflex decreases with rigidity, and co-contraction is seen in both articular movement protagonistic muscle and antagonistic muscle (Lance, 1980). With flaccidity, muscle tone decreases (Pendleton, 2006). SAMO reproduces these abnormal muscle tones. In spastic mode, the motor rotational strength expressing protagonistic muscle that is passively dependent on velocity rises, and the motor rotational strength expressing antagonistic muscle lowers. In rigid mode, the motor rotational strength for both protagonistic muscle and antagonistic muscle rises. In flaccid mode, motor active rotation is disabled. The application controlling the actuator uses LabVIEW by National Instruments, and records programs driving the actuator to express spasticity, rigidity, and flaccidity in patients with impaired movement. An application for analyzing arm motion information can convert the exercise therapy applied to the arm by a person into joint angles, and actuator voltage values into force, and then record them. In addition, it can promptly analyze the articular movement applied by a person to the arm and display it (Figure 3).



| Item | |
|---|---|
| Name | beginner |
| Use example | Right |
| Recording time | 15 sec |
| Save location | C:¥ |
| mode | spastic |

**Figure 3:** Screen showing recording of manual exercise therapy applied to SAMO Motion information when the arm robot is passively moved is analyzed, SAMO's elbow joint angles and the manual resistance value of the practitioner is shown on a graph, and the robot's motions can be displayed in real time with 3D animation on the right split screen.

## 2. Example creation

To create exercise therapy examples, an occupational therapist with 10 years of clinical experience performed 2 repetitions × 5 sets of exercises passively flexing and extending the elbow joint of the robot from maximum extension (0°) to maximum flexion (90°). Assuming SAMO's pathology to be spasticity, the occupational therapist taught passive movement of the arm robot with the intent of moving the elbow joint of a patient with spasticity. The obtained joint angle changes and joint force from the 10 repetitions were averaged to create examples. The examples presented is this study are from various exercise therapies.

## 3. Passive articular movement exercises

In this study, we displayed the values of joint angle and force during the articular movement of the robot by a therapist as examples on a liquid crystal screen and set the task of conducting the exercise therapy on the robot accordingly. In other words, this task included visual and proprioceptive components where the force applied to the joint was adjusted according to the sense of resistance received by the subject from the robot.

During passive articular movement exercises, the joint angles in examples were replayed on a liquid crystal display placed 80 cm away from the subject, while a cursor reflecting the current joint angles of the arm robot was displayed in real time. The subjects were a veteran occupational therapist with 10 years of clinical experience and three fourth-year university students prior to clinical training. The subjects were instructed to passively flex and extend the elbow joint of the arm robot while following the joint angle changes in the examples. Joint flexions were performed for 2 repetitions × 5 sets. Further, the occupational therapist, who became the subject, was the same occupational therapist who created the examples.

This study was approved by the ethics committee of Saitama Prefectural University, and was conducted according to the Helsinki Declaration. In addition, all the subjects were fully apprised of the details of the experiment in advance, and provided written consent to participate in the study.

## 4. Analysis

To compare the changes in the angle when the elbow joint of SAMO was moved by the occupational therapist and the students, we calculated the maximum flexion angle, maximum extension angle, maximum angular velocity, maximum angular acceleration, and average jerk of the elbow joint and compared the results from the occupational therapist and the students using the two-sample t-test. Further, we analyzed the joint angle changes in the arm robot and the joint force applied to the arm by a person. To evaluate the consistency of the joint angle changes in the examples, and from the occupational therapist and students, we averaged the respective joint angle data for the occupational therapist and students, and then used Pearson correlation coefficient and interclass correlation coefficient for comparison.

In addition, to evaluate the characteristics of the joint angle changes in the examples and those obtained from the occupational therapist and students, and the joint force applied to the arm by a person, we approximated the following simple harmonic motion model (Schneck, 1990; Osler, 2006) through the least squares method with the averaged joint angle and joint force data:

$$f(t) = A\sin(\omega t + \varphi)$$

where $A$ represents amplitude, $\omega$ represents angular frequency, and $\varphi$ represents phase. In addition, we used coefficient of determination in the simple harmonic motion model and approximate evaluation of measured joint angles. We used SPSS Statistics 23.0 for statistical analysis at a significance level of $p < 0.05$.

## Results

Table 1 shows the maximum flexion angle, maximum extension angle, maximum angular velocity, maximum angular acceleration, and average jerk of the elbow joint of SAMO when passive exercise therapy was performed by the occupational therapist and the students. The maximum flexion angle of the elbow joint was significantly smaller in the case of the students compared to the occupational therapist, whereas the maximum extension angle was larger. The maximum angular velocity and maximum angular acceleration when moving the elbow joint of SAMO were significantly higher in the case of the students.

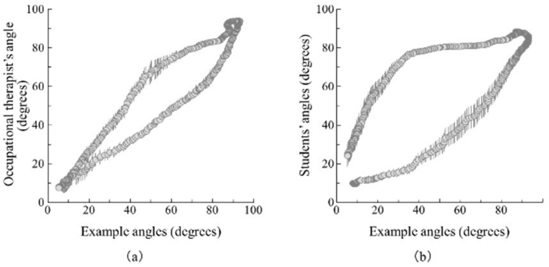


**Figure 4:** Changes in joint angles in the examples, and from the occupational therapist and students. (a) Joint angle changes in the examples and from the occupational therapist. (b) Joint angle changes in the examples and from students. Gray circle is the mean value of joint angles every 10 ms, the error bar is standard error.

Figure 4 shows the joint angle changes in the examples, and the joint angle changes from the occupational therapist and students. In the passive articular movement exercises in this study, subjects were taught to passively flex and extend the elbow joint of the arm robot following the joint angle changes in the examples, such that the joint angles of the occupational therapist and students showed a spindle-shaped distribution somewhat slower

**Table 1:** Kinematics-related motion during passive exercise therapy by occupational therapist and the students

| | Occupational Therapist | Students | *p-value* |
|---|---|---|---|
| Maximum flexion angle (deg) | 93.98±2.27 | 88.60±4.05 | 0.012* |
| Maximum extension angle (deg) | 0.28±0.22 | 4.62±4.21 | 0.001** |
| Maximum angular velocity (deg/s) | 352.00±29.50 | 446.00±102.53 | 0.005** |
| Maximum angular acceleration (deg/$s^2$) | 33800.00±3114.48 | 42200.00±10831.17 | 0.015* |
| Average jerk (deg/$s^3$) | 175443.32±6596.71 | 169584.74±14317.20 | 0.394 |

*: $p < 0.05$, **: $p < 0.01$

**Table 2:** Comparison according to simple harmonic motion model trend line of elbow joint angles and joint force changes in the examples and applied by occupational therapist and students to SAMO.

| | Examples | Occupational therapist | Students |
|---|---|---|---|
| Joint angles | | | |
| $A$ | 96.86 | 97.65 | 93.04 |
| $\varphi$ | 0.09 | 0.01 | 0.01 |
| $\omega$ | 0.64 | 0.64 | 0.57 |
| $R^2$ | 0.961* | 0.983* | 0.963* |
| Joint force | | | |
| $A$ | 1.96 | 2.13 | 2.07 |
| $\varphi$ | 21.8 | 0.24 | -0.32 |
| $\omega$ | -0.67 | 0.67 | 0.76 |
| $R^2$ | 0.839* | 0.777* | 0.671* |

$A$: amplitude, $\omega$: angular frequency, $\varphi$: phase, $R^2$: coefficient of determination, *$p < 0.0001$

than in the examples. A significant correlation was found in the arm robot joint angle changes in the examples and from the occupational therapist and students (examples and occupational therapist: $r = 0.972$, $p < 0.0001$; examples and students: $r = 0.807$, $p < 0.0001$). In addition, the interclass correlation coefficient in the examples and with the occupational therapist was 0.985 ($p < 0.0001$), whereas the interclass correlation coefficient in the examples and with the students was 0.880 ($p < 0.0001$).

When we approximated a simple harmonic motion model with the joint angles in the examples and obtained from the occupational therapist and students, the coefficient of determination was high for both the models and the actual measured values: examples 0.961 ($p < 0.0001$), occupational therapist 0.983 ($p < 0.0001$), students 0.963 ( $p < 0.0001$). When we

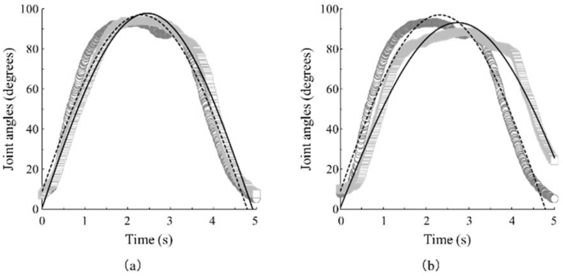


**Figure 5:** Comparison of actual measured values and predicted model values for articular movement in the examples and from the occupational therapist and students. (a) Comparison of actual measured values and predicted model values for joint angles in the examples and from the occupational therapist. (b) Comparison of actual measured values and predicted model values for joint angles in the examples and from students. Gray circle is the actual measured values in the examples, White square is the actual measured values for joint angles from the occupational therapist or students, the dotted line is the simple harmonic motion model curve for the examples, and the solid line is the simple harmonic motion model curve for the occupational therapist or students.

compared the amplitude ($A$), angular frequency ($\omega$), and phase ($\varphi$) of each group, the frequencies of the students were smaller than those in the examples and that of the occupational therapist, and the cycle of joint angle changes was prolonged (Table 2, Figure 5).

Figure 6 shows the joint force in the examples and the joint force changes from the occupational therapist and the students. A significant correlation was found in the arm robot joint force changes in the examples and from the occupational therapist and students (examples and occupational therapist: $r = 0.960$, $p < 0.0001$; examples and students: $r = 0.897$, $p < 0.0001$). In addition, the interclass correlation coefficient for the joint force changes in the examples and from the occupational therapist was 0.970 ($p < 0.0001$), whereas the interclass correlation coefficient for the examples and students was 0.929 ($p < 0.0001$).

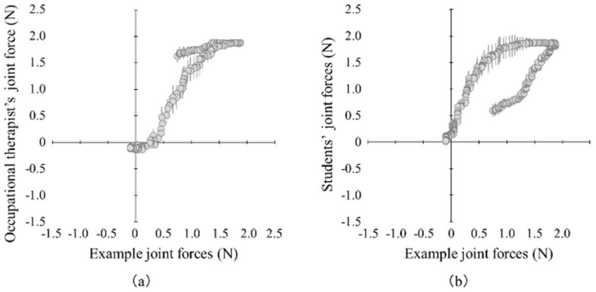


**Figure 6:** Changes in joint force in the examples and for the occupational therapist and students. (a) Joint force changes in the examples and from the occupational therapist. (b) Joint force changes in the examples and from students. Gray circle is the mean value of joint every 10 ms, the error bar is standard error.

When we approximated a simple harmonic motion model with the joint force in the examples and obtained from the occupational therapist and students, the coefficient of determination was high for both the models and the actual measured values: examples 0.839 ($p < 0.0001$), occupational therapist 0.777 ($p < 0.0001$), students 0.671 ($p < 0.0001$). When we compared the amplitude ($A$), angular frequency ($\omega$), and phase ($\varphi$) of each group, the joint force changes of the students had more prolonged cycles than those in the examples and that of the occupational therapist (Table 2, Fig. 7).

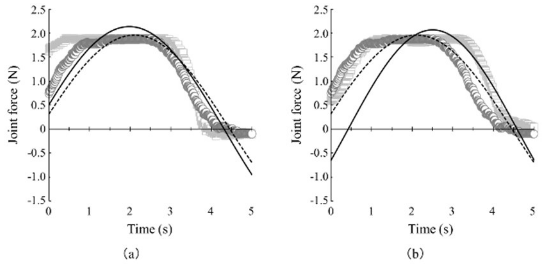


**Figure 7:** Comparison of actual measured values and predicted model values for joint force in the examples and from the occupational therapist and students. (a) Comparison of actual measured values and predicted model values for joint force in the examples and from the occupational therapist. (b) Comparison of actual measured values and predicted model values for joint force in the examples and from students. Gray circle is the actual measured values in the examples, White square is the actual measured values for joint force from the occupational therapist or students, the dotted line is the simple harmonic motion model curve for the examples, and the solid line is the simple harmonic motion model curve for the occupational therapist or students.

## Discussion

In this study, we compared the exercise therapy skill of students to that of an occupational therapist. The results showed that the range of motion when moving the elbow joint of SAMO was significantly smaller in the case of the students compared to that of the occupational therapist, whereas the movement speed applied on SAMO was higher. The frequencies of the articular movements of the students applied to SAMO were smaller than those in the examples and those of the therapist, and the cycle of joint angle changes was prolonged. This suggests that, compared to the therapist, the students did not fully learn passive exercises corresponding to the passive abnormal muscle tone of the elbow joint flexor group and extensor group.

The study of motor skill such as in manual exercise therapy has three phases: ① cognitive, ② associative, and ③ autonomous (Fitts, 1964; Fitts, 1967). The cognitive phase is the initial phase of learning, in which students come to understand what exercises are needed to acquire motor skills. Students in this phase are inattentive, inaccurate, slow, and inefficient regarding exercises. In the associative phase, students are in an intermediate phase, in which their learning changes from “What to do?” to “How to do?” The autonomous phase is the final phase of learning, in which students become unconsciously capable of performing exercises, and can do them without unnecessary motion (Fitts, 1964, Schmidt, 2008). In our experiment, we assumed that students were in the cognitive phase, in which they have little opportunity for coming into contact with actual patients, but may come to understand exercise therapy conforming to SAMO pathology exercises by turning their attention to performing elbow joint exercises on SAMO.

Four types of learning curves may be found in the study of motor skills: negative accelerating curve learning, in which skills improve significantly in the initial stage of learning but then improvement decreases; positive accelerating curve learning, in which skills improve little in the initial stage but then rapidly improve; and S-curve learning in which skills improve little in the initial stage but then skill improvement flattens out and then gradually decreases (Singer, 1968). Hence, learning curves are varied, and it is believed that motor skill learning requires a certain amount of learning time. Similarly, mastery of manual exercise therapy may require learning time to experience contact with actual patients. It may be possible to estimate how much learning time is required by investigating the number of clinical experience hours of persons approximately capable of standard manual exercise therapy skill. A future study might involve using SAMO to further examine the exercise therapy skills of experts and novices, and then creating an algorithm for distinguishing differences between the two groups.

In this study, we displayed the values of joint angle and force, when an articular movement was applied to a robot by a therapist, as examples on a liquid crystal screen and assigned the students and the occupational therapist the task of performing exercise therapy on the robot accordingly. This meant that the subjects were involved in two tasks simultaneously, sensing themselves the muscle tone expressed by robots, while performing manual exercise therapy according to examples displayed on the SAM screen. It was known that if the two tasks exceeded a subject’s individual skill, there might be confusion in one or both actions (Woollacott, 2002). This depended upon the limits of a person’s attentional resources (Baddeley, 1974). It is believed that attention to tasks contributed to joint angle and joint force cycles applied by the students to the robot that were longer than in the examples. Based on the present data, it is felt that the level to which the manual exercise therapy performed by students approximated examples is an indicator of learning results.

In this study, the occupational therapist who created the examples was also the subject. Considering that it is easier for the person who created the examples to reproduce his/her movement than to reproduce the movement of others, it is possible that its correlation with the examples is over estimated compared to the students. On the other hand, since the range of the elbow joint movement of SAMO was smaller in the case of the students compared to the occupational therapist, it can be considered that the exercise therapy skills of the students were inadequate compared to those of the occupational therapist.

From the results of this study, it is implied that, compared to the occupational therapist, the students have not sufficiently mastered the passive exercises corresponding to passive abnormal muscle tone in the elbow flexor muscle group and extensor muscle group. In addition, students inexperienced in manual exercise therapy risk causing problems for patients the more times they come in contact with them. They may inadvertently increase patient anxiety and stress, or occasionally cause them pain. SAMO can reproduce spastic and rigid passive pathology exercises. SAMO may serve as a mock patient for students, and may be adopted for simulation education in manual exercise therapy. Therefore, learning guidelines for manual exercise therapy using SAMO need to be drafted, followed by empirical research into practical skills education.

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## References

Baddeley, A. D., Hitch, G., 1974. Working memory. Psychology of Learning and Motivation, 8, 47-89.

Bandy, W. D.,1994. The effect of time on static stretch on the flexibility of the hamstring muscle. Phys. Ther. 74, 845-850.

Barnes, M. P., Johnson, G. R., 2008. Upper motor neuron syndrome and spasticity, second ed. Cambridge: Cambridge University Press.

Cameron, M. H., 2012. Physical agents in rehabilitation from research to practice, fourth ed. Philadelphia: Saunders.

Feland, J. B., Myrer, J. W., Schulthies, S. S., Fellingham, G. W., Measom, G. W., 2001. The effect of duration of stretching of the hamstring muscle group for increasing range of motion in people aged 65 years or older. Phys. Ther. 81, 1110-1117.

Fitts, P. M., 1964. Perceptual-motor skill learning. In A. W. Melton (Ed.), Categories of human learning (pp. 243-285). New York: Academic Press.

Fitts, P. M., Posner, M. I., 1967. Human performance. Belmont, Wadsworth.

Hagbarth, K. E., Hägglund, J. V., Nordin, M., Wallin, E. U., 1985. Thixotropic behavior of human finger flexor muscles with accompanying changes in spindle and reflex responses to stretch. J. Physiol. 368, 323-342.

Harden, R. M., 1988. What is an OSCE? Med. Teach. 10, 19-22.

Harden, R. M., 2002. Learning outcomes and instructional objectives: Is there a difference? Med. Teach. 24, 151-155.

Hodgetts, S., Hollis, V., Triska, O., Dennis, S., Madill, H., Taylor, E., 2007. Occupational therapy students' and graduates' satisfaction with professional education and preparedness for practice. Can. J. Occup. Ther. 74, 148-160.

Lance, J. W., 1980. Spasticity: Disordered motor control. In R. G. Feldman, R. R. Young, W. P. Koella, (Eds.), (pp. 487-489). Chicago: Year Book Medical Pubs.

Nathan, P., 1973. Some comments on spasticity and rigidity. In J.E. Desmedt (Ed.), New developments in electromyography and clinical neurophysiology (pp. 13-14). Karger Publishers.

Oddeen, I., Knutsson, E., 1984. Evaluation of the effects of muscle stretch and weight load in patients with spastic paraplegia. Scand. J. Rehabil. Med. 13, 117-121.

Osler T. J., Chandrupatla T. R., 2006. Using simple harmonic motion to help in the search for tautochrone curves. Int. J. Math. Educ. Sci. Technol. 37, 1, 104-109.

Pedretti, L. W., 1996. Occupational therapy: Practice skills for physical dysfunction, fourth ed. St Louis, MO: Mosby-Yearbook Inc.

Pendleton, H. M. H., Shultz-Krohn, W., 2006. Pedretti's occupational therapy: Practice skills for physical dysfunction, sixth ed. Mosby Elsevier: St. Louis, MO.

Rybski, M., 2004. Kinesiology for occupational therapy. Thorofare, New Jersey: Slack.

Schmidt, R. A., & Wrisberg, C. A., 2008. Motor learning and performance: A situation-based learning approach, fourth edition. Champaign, IL: Human Kinetics.

Schneck D. J., 1990. Engineering Principles of Physiologic Function, first ed. New York University Press, NY.

Singer, R. N., 1968. Motor Learning and performance. New York: Macmillan.

Takanobu, H., 2008. Dental patient robot. In V. Bozovic (Ed.), Medical robotics (pp. 443-456). Shanghai: I-Tech Education and Publishing.

Tanzawa, T., Futaki, K., Kurabayashi, H., Goto, K., Yoshihama, Y., Hasegawa, T., Yamamoto, M., Inoue, M., Miyazaki, T., Maki, K., 2013. Medical emergency education using a robot patient in a dental setting. Eur. J. Dent. Educ. 17, e114-e119.

Woollacott, M., Shumway-Cook, A., 2002. Attention and the control of posture and gait: A review of an emerging area of research. Gait Posture. 16, 1-14.

Yeh, C. Y., Chen, J. J., Tsai, K. H., 2007). Quantifying the effectiveness of the sustained muscle stretching treatments in stroke patients with ankle hypertonia. J. Electromyogr. Kinesiol. 17, 453-461.