Comparison of Manipulative Indicators of Students and Therapists Using a Robotic Arm

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Abstract

Background: The purpose of this study was to clarify the motion therapy elements necessary for the education of students through comparison of the therapeutic motion techniques of therapists and students using an educational arm robot (Samothrace: SAMO) set with varying degrees of muscle tone pathology.

Methods: The participants included eight therapists with more than five years of clinical experience and 25 fourth-year students from occupational therapy training schools who had completed their clinical practice. The therapeutic motion therapy task was a reciprocating exercise in which the elbow joint of SAMO was flexed from an extended position and then re-extended. This was performed three times for each of the three types of muscle tone intensities (mild, moderate, and severe), for a total of nine repetitions. The peak velocity, peak angle ratio, peak velocity time, and movement time were recorded using SAMO while the subjects performed the therapeutic motion therapy task. These data were compared using analysis of covariance.

Results: The SAMO elbow joint kinematic data generated by therapists were significantly different than those of students for different muscle tones. It was clear from multiple comparisons that the therapeutic motion techniques of students were associated with higher peak velocity, smaller peak angle ratio, and shorter peak velocity time and movement time than those of therapists.

Conclusion: The therapeutic motion techniques applied by the students in response to the muscle tone condition of the arm robot were different from those applied by therapists, suggesting that the students were not able to perform the therapeutic motion techniques in response to the degree of the muscle tone intensity in the same way that an expert could. Based on the results, when students learn therapeutic motion techniques, they should be taught to 1) deal with multiple muscle tone intensities and 2) reduce the speed of joint movement applied to the patient, extend the exercise time, and ensure maximum range of joint movement. These were the suggested guiding factors.

Background

Recently, outcome-based education (OBE) [1], which emphasizes outcomes such as the characteristics of required abilities, has become a global standard for medical education [2, 3]. One of the teaching methods used is simulation education. Simulation education has already been established in fields other than the medical field, such as the use of flight simulators for pilots [4] and management simulations for executives [5], and its use has begun to spread in the medical field in terms of surgery [6]. In the field of dentistry, simulation education and technical evaluation [7–9] using patient robots capable of autonomous tongue movement, salivation, the vomiting reflex, and simple conversation is considered to be effective.

Evaluations and technical interventions are performed in the rehabilitation field similarly as they are provided to patients in the surgical and dental fields. For this reason, students studying rehabilitation are required to have access to easy-to-understand education, such as simulation education incorporating patient robots and the presentation of motor elements that must be achieved. In the teaching of therapeutic motion techniques conducted in rehabilitation, motor elements, such as the amount of load applied to the patient's body and the speed of movement, should be quantitatively presented to the students.

To solve this problem, an educational arm robot was developed to reproduce the muscle tone pathology of stroke patients and record the joint movements applied to the robot (development code Samothrace: SAMO, Patent No. 6307210) (Fig. 1) [10]. Using SAMO, it is possible to replicate the practice of therapeutic motion therapy. The robot simulates a state similar to the pathological movement of a patient with stroke, which can be reproduced as many times as necessary. Recently, SAMO has been used to create identifiers that distinguish between therapists and students [11]. Therefore, as a new learning method for therapeutic motion therapy, students can visually confirm the therapeutic motion techniques that they have performed on SAMO, compare them with the therapeutic motion techniques of therapists, and perform repetitive exercises to replicate the therapists' techniques more closely. However, previous studies have only compared the therapeutic motion techniques of therapists and students for one type of muscle tone pathology [10, 11].

The Modified Ashworth Scale (MAS) [12], which is widely used to evaluate muscle tone pathology, indicates the degree of muscle tone pathology in six stages based on the resistance of the patient when the limbs are passively moved. The degree of muscle tone pathology varies among patients, and therapists perform therapeutic motion therapy that is appropriate for each patient's muscle tone pathology. In other words, the features of joint movement that students should be aware of during therapeutic motion therapy should vary for different muscle tones, and students should acquire therapeutic motion techniques that are appropriate for the muscle tone pathology of each patient. It is thus necessary to clarify the features of the therapeutic motion techniques used by skilled therapists for various muscle tones and provide them as an index of practice for students. The purpose of this study was to compare the therapeutic motion techniques of therapists and students using a robot set to simulate different degrees of muscle tone pathology, as well as to clarify the motor elements that should be taught to students.

Methods

1) Subjects

The subjects of this study included occupational and physical therapists (therapists) with more than five years of clinical experience and fourth-year students (students) who had undergone clinical training at an occupational therapist training school. Therapists have more than five years of clinical experience because of the period that they are expected to complete as part of the basic and incumbent training as specified by the Japanese Association of Occupational Therapists, and the period for which they are eligible for the optional program for authorized occupational therapists [13]. In addition, a standard minimum of five years of experience required to become a clinical training instructor [14, 15]. Students who were in the fourth year of training were chosen because by that time, they had learned about therapeutic motion techniques in both the training school and in a clinical setting, and it was supposed that they possessed knowledge and skill levels close to that of therapists. The sample size for this study was estimated using the statistical software package G*

Power (a tool used to perform statistical power analysis) based on available data and subject to the set levels of $\alpha = 0.05$ and $1-\beta = 0.80$ [16]. The minimum number of required participants was 18.

This study was approved by the Saitama Prefectural University Ethics Committee (approval no. 27112) and implemented in accordance with the Declaration of Helsinki. All participants received a thorough explanation of the experimental content in advance and provided written consent for participation in the study.

2) Therapeutic motion technique task and measurement methods

The subjects were asked to perform the task of maximal flexion of the SAMO elbow joint from the position of maximum extension, which was the starting limb position, and then to return it to the starting limb position. The posture of the subject performing the therapeutic motion therapy task, the speed of movement, and the subject's grip position on the robot arm were unrestricted. In the therapeutic motion therapy task, the pathological condition of the elbow joint of SAMO was set, in turn, to each of three stages: mild, moderate, and severe. Each task was performed three times for a total of nine repetitions. The muscle tone of the SAMO was set by changing the axial value of the actuator. Mild tone involved a resistance value of 2.4 N, moderate corresponded to a resistance value of 3.9 N, and severe corresponded to a resistance value of 5.4 N. The three types of muscle tone intensities were randomly simulated for each subject (Fig. 2).

The elbow joint angular change and exercise time applied to the robot arm by the subject during the therapeutic motion therapy task were both recorded by SAMO at a sampling rate of 100 Hz. From the recorded elbow joint angular change and exercise time, the peak velocity, peak angle ratio, peak velocity time, and movement time during flexion and extension were calculated for each of the three types of muscle tone. These data were used in the analysis.

3) Analysis

The peak angle ratio during flexion and extension of the elbow joint was calculated by dividing the recorded maximum angle by the maximum possible angle of the SAMO. The maximum possible flexion and extension angles of the SAMO were measured as calibration data for each of the three types of muscle tone before performing the experimental measurements. Movement time was defined as the interval from the onset of the exercise to the end of the exercise. The onset of the exercise was determined based on the average value of the resting angular velocity for the 3 s prior to the task movement and was set as the value associated with the time exceeding that value by 50 ms or more. The end of the exercise was defined as the time when the task movement was completed and the joint angle became constant.

Subject characteristics were compared using a two-sample t-test. To clarify the motor characteristics of therapeutic motion therapy based on the participant groups (therapists and students) and muscle tone intensity (mild, moderate, severe), the peak velocity, peak angle ratio, peak velocity time, and movement time associated with the three types of muscle tone during flexion and extension were compared using analysis of covariance between and within the groups. The intergroup comparison compared the therapist and student data for each muscle tone intensity, and the intragroup comparison compared the muscle tone intensity data within each group of therapists and students. When a significant difference was found, multiple comparisons were performed using Bonferroni's method. In addition, the number of male and female study participants differed in this present study. Sex-related muscular strength differences, such as grip strength, were observed in previous studies [17]. The possibility that gender may affect data comparison was thus taken into account through the addition of gender to the covariates. Statistical analysis was performed using R 4.0.1 (R Development Core Team, Austria) and SPSS Statistics 25.0 (International Business Machines Corporation, USA), with a statistical significance level of less than 5%.

Results

1) Subject demographic data

The subjects who participated in this study included eight therapists (7 males and 1 female) and 25 students (9 males and 16 females) (Table 1). The clinical experience of the therapists consisted of 12 ± 4 years after obtaining their licenses. Fig. 3 shows typical examples of kinematic data for the therapeutic motion therapy of four therapists and four students. The greatest elbow joint angle ratio during the therapeutic motion therapy was lower in students than in therapists. Among students, it was lower for the moderate and severe muscle tone intensities than for mild intensity. In addition, the velocity during therapeutic motion therapy was higher in students than in therapists. Among students, velocity was higher for mild muscle tone intensity than for severe.

2) Comparison of kinematic data during elbow flexion of arm robot

Table 2 and Fig. 4 show the comparison results of the kinematic data of the two groups (therapists and students) for the three types of muscle tone (mild, moderate, and severe). The peak velocity of elbow flexion in SAMO had a major effect depending on the group and muscle tone intensity ($p < .001$, $\text{partial } \eta^2 = .039-.064$) but did not involve any interaction ($p = .889$). As a result of multiple comparisons, the peak velocity during flexion was found to be significantly higher in the student group than in the therapist group when the muscle tone intensity was mild and moderate ($p = .016-.033$, $d = .56-.67$). In addition, the peak velocity during flexion did not differ among therapists for the three types of muscle tone, but it was significantly higher in the student group when the muscle tone intensity was mild and moderate than when it was severe ($p = .011$, $p < .001$, $d = .46-.82$).

The peak angle ratio of elbow flexion in SAMO had a major effect depending on the group ($p < .001$, $\text{partial } \eta^2 = .155$) but not depending on muscle tone intensity ($p = .065$), and it did not involve any interaction ($p = .174$). As a result of multiple comparisons, it was found that the peak angle ratio of the student group was significantly smaller than that of the therapist group for all muscle tone intensities. ($p = .003$, $p < .001$, $d = .93-1.11$).

The peak velocity time had a major effect depending on the group ($p = .006$, $\text{partial } \eta^2 = .025$) but not depending on muscle tone intensity ($p = .186$), and it did not involve any interaction ($p = .362$). As a result of multiple comparisons, when the muscle tone intensity was mild and severe, the peak velocity time of the

student group was found to be significantly shorter than that of the therapists group. ($p = .024$ and $.025$, $d = .38$).

The movement time had a major effect depending on the group ($p < .001$, $partial \eta^2 = .105$) but not depending on muscle tone intensity ($p = .423$), and it did not involve any interaction ($p = .457$). As a result of multiple comparisons, the movement time of the student group was found to be significantly shorter than that of the therapist group for all muscle tone intensities ($p = .004$, $p < .001$, $d = .59-.77$).

3) Comparison of kinematics data during elbow extension of arm robot

The peak velocity of elbow extension in SAMO had a major effect depending on the group and on muscle tone intensity ($p = .003$, $p < .001$, $partial \eta^2 = .030$ and $.103$), but it did not involve any interaction ($p = .867$). As a result of multiple comparisons, it was found that when the muscle tone intensity was severe, the peak velocity of the student group was significantly higher than that of the therapist group ($p = .030$, $d = .55$). In the therapist group, the peak velocity was significantly higher when the muscle tone intensity was mild than when it was severe ($p = .002$, $d = 1.10$). In the student group, the peak velocity was significantly higher when the muscle tone intensity was mild and moderate than when it was severe, and it was also significantly higher when the muscle tone intensity was mild than when it was moderate ($p = .010 - .023$, $p < .001$, $d = .44 - .87$).

The peak angle ratio of elbow extension in SAMO had a major effect depending on the group and on muscle tone intensity ($p < .001$, $partial \eta^2 = .061 - .063$) and involved interaction ($p = .043$, $partial \eta^2 = .022$). As a result of multiple comparisons, the peak angle ratio was found to be significantly smaller in the student group than in the therapist group when the muscle tone intensity was severe ($p < .001$, $d = .79$). There was no difference in peak angle ratio based on the muscle tone intensity within the therapist group ($p = .808 - 1.000$). However, within the student group, the peak angle ratio was significantly smaller when muscle tone intensity was severe than when it was mild and moderate ($p < .001$, $d = .56 - .93$).

The peak velocity time of elbow extension in SAMO had a major effect depending on the group and on muscle tone intensity ($p = .003$, $p < .001$, $partial \eta^2 = .039 - .059$) but did not involve any interaction ($p = .963$). As a result of multiple comparisons, the peak velocity time in the student group was found to be significantly shorter than that of the therapist group for all muscle tone intensities ($p = .005 - .014$, $d = .26 - .46$). The peak velocity time in the student group was significantly shorter when the muscle tone intensity was mild than when it was severe. ($p = .003$, $d = .50$). Within the therapist group, no difference was found in peak velocity time with respect to muscle tone intensity ($p = .138 - 1.000$).

The movement time of elbow extension in SAMO had a major effect depending on the group and on muscle tone intensity ($p = .006$, $p < .001$, $partial \eta^2 = .035 - .097$), and it did not involve any interaction ($p = .312$). As a result of multiple comparisons, the movement time of the student group was found to be significantly shorter than that of the therapist group for all muscle tone intensities ($p = .014$, $p < .001$, $d = .41 - .75$). There was no difference in movement time due to muscle tone intensity in the student group ($p = .263 - 1.000$), but the movement time in the therapist group was significantly longer when the muscle tone intensity was severe than when it was mild ($p = .021$, $d = .67$).

Discussion

In this study, we analyzed kinematic data obtained from therapists and students performing therapeutic motion therapy on the upper limb under varying conditions of muscle tone pathology severity that were simulated with a robot. The results indicated that, in terms of the therapeutic motion therapy applied to the robot by students, the peak velocity of elbow flexion and extension was higher, the peak angle ratio was smaller, and the peak velocity and movement times were shorter than those of therapists. The results of this study were similar to those of previous studies conducted under the condition of one type of muscle tone intensity being simulated by the robot [10, 11]. Based on these results, it is suggested that when instructors teach upper limb therapeutic motions to students, it would be better to teach them to reduce the speed of joint movement applied to the patient, extend the exercise time, and maximize the range of joint movement, regardless of the muscle tone intensity of the patient. It is recommended that these motor elements should be presented to students as OBE of therapeutic motion therapy of the upper limb.

1) Therapeutic motion techniques of therapists and students

When the elbow joint of the arm robot was flexed, students demonstrated a higher peak velocity than therapists compared to the case when the muscle tone intensity was mild or moderate. Similarly, when the elbow joint was extended, the student group moved the joint rapidly when the degree of muscle tone was severe. In contrast, the peak velocity time was longer for therapists than for students when the muscle tone was mild and severe during flexion and for all muscle tone intensities during extension. This result suggested that the students did not change their movement time even if the muscle tone intensity of the robot changed, and that they performed therapeutic motion therapy that could easily cause a stretch reflex. In addition, the movement time of therapists was longer than that of students during flexion and extension for all muscle tone intensities. Because muscle tone is speed-dependent [18], it was considered that therapists performed therapeutic motion therapy more carefully, paying more attention to muscle tone, as compared to students. Consequently, students were at risk of initiating the patient's stretch reflex during therapeutic motion therapy that involved flexing an elbow joint with mild or moderate muscle tone intensity or extending an elbow joint with severe muscle tone intensity.

The range of joint motion applied to the robot by the students was smaller than that of the therapists during flexion under all muscle tone intensities and during extension under severe muscle tone intensity. Joint inactivity can cause contracture [19]. In patients with severe spastic contractions and who experienced difficulties in voluntary movement, therapeutic motion therapy is performed to passively maximize joint movement. It was suggested that the therapeutic motion therapy performed by students would not prevent joint contracture in patients due to insufficient joint momentum, unlike the motion therapy performed by therapists.

2) Toward teaching therapeutic motion techniques to students

From the results of this study, the problems associated with student therapeutic motion techniques for elbow joints with abnormal muscle tone were noted as having the following characteristics: 1) When the muscle tone intensity was mild and moderate during flexion and when it was severe during extension, rapid joint movement was observed. 2) The range of joint movement was small for all muscle tone intensities during flexion and for severe muscle tone intensity during extension. 3) The exercise time for flexion and extension was short, regardless of the muscle tone intensity.

In the past, students learned therapeutic motion techniques through student-to-student simulation on campus or during clinical practice at a hospital. During clinical training at hospitals, instructors have taught that the speed at which the patient's upper limbs are moved and the range of the exercise should be adjusted according to the patient's condition. However, in actual patient joint movement, there has been no alternative other than imitating the instructor to achieve correct speed, exercise time, and range of exercise. Educational arm robots such as the SAMO, which can be used to reproduce changing muscle tone intensity, can be used to teach therapeutic motion techniques. Using a robot, the motor element data of therapists can be presented to the student as a target, in addition to the motor elements of therapeutic motion therapy performed by the students themselves. This introduces the possibility that the learning effect can be enhanced. The educational improvements that could be achieved by presenting these motor elements to students through OBE programs associated with upper limb therapeutic motion therapy should be verified in a future study.

3) Limitations of this study

The three types of muscle tone resistance values used in this study were not based on measurements of the actual muscle tone resistance values of stroke patients. Because no previous study has determined the actual muscle tone resistance values of stroke patients, we set the patient's muscle tone resistance values arbitrarily. In future studies, it will be necessary to verify whether the resistance values of an actual patient can be reproduced using SAMO. Because the height and weight of the subjects were not measured in this study, it could not be ascertained whether these variables had an effect on the data comparison. Therefore, in a future study, the height and weight of subjects should be measured and statistically processed.

Conclusion

The elbow joint of a robotic arm which could be used to simulate changes in muscle tone intensity was used to record the kinematic data generated by therapists and students. These data were significantly different for all monitored variables. The joint movements applied by the students in response to the muscle tone intensity of the robot differed from those of therapists, suggesting that the students were not able to perform therapeutic motion techniques appropriate to the muscle tone intensity in the same way that experts could. These results suggest that, when teaching students therapeutic motion techniques, 1) they should be taught to adapt to multiple muscle tone intensities, and 2) the peak velocity, peak angle ratio, peak velocity time, and movement time motion elements should be noted.

Abbreviations

SAMO: Samothrace

OBE: Outcome-Based Education

MAS: Modified Ashworth Scale

Declarations

1) Funding

This work was supported by a Grant-in-Aid for Leading-edge Industry Design Project provided by the Saitama Prefecture 2015–2017 to HT, and by the Grant-in-Aid JSPS KAKENHI 17K13059 and 20K11286 provided to KY. These funders no specific role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript.

2) Conflicts of interest/Competing interests

There are no conflicts of interest to declare.

3) Ethics approval

This study was approved by the Saitama Prefectural University Ethics Committee (approval no. 27112) and implemented in accordance with the Declaration of Helsinki.

4) Consent to participate

All participants were thoroughly explained the experimental content in advance, and they provided written consent for participation in the study.

5) Consent for publication

The Author warrants and represents that the contribution does not infringe upon any copyright or other rights, and that it does not contain infringing or other unlawful matter, that he/she was the sole and exclusive owner of the rights herein conveyed to the publisher.

6) Availability of data and material

Subject data, except for personal information, will be provided in excel files upon researcher's request with the approval of the Ethics Committee. If a researcher wants to use the data, request should be made by e-mail to the corresponding author.

7) Code availability

The SAMO application was written in LabVIEW. This app is a product of Peritex Inc.

8) Authors' contributions

Authors' contributions: KY and HT designed the study and wrote the initial draft of the manuscript. OA, TK, and TY contributed to the analysis and interpretation of data and assisted in the preparation of the manuscript. All authors contributed to data collection. All authors have read and approved the manuscript.

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Tables

Table 1 Subject characteristics

	Therapists (n = 8)	Students (n = 25)	Statistics	df	p value	Effect size
Age (years)	36 ± 7	22 ± 1	$t = 5.552$	7.033	< .001*	$d = 4.07$
Sex (male/female)	7 / 1	9 / 16	$\chi^2 = 6.436$	1.000	.017*	$V = .17$
Years after registered	12 ± 4	0 ± 0	$t = 9.262$	7.000	< .001*	$d = 6.83$

Statistics: Values are calculated using student T-tests and χ^2 for comparisons. * $p < .05$.

Table 2 Comparison of therapeutic techniques applied by students and therapists using a robot

Variables		Therapists (n=8)			Students (n=25)			Analysis of covariance					
		Muscle tone intensity			Muscle tone intensity			Main effect of group				Main effect	
		mild	moderate	severe	mild	moderate	severe	df	F	p	Partial η^2	df	F
Flexion	Peak velocity	90.2±41.6	78.2±37.3	60.8±29.6	121.2±47.5	106.2±52.8	84.6±41.2	1	11.630	<.001*	.039	2	9.94
	Peak angle ratio	97.0±3.4	96.1±3.6	96.3±4.1	89.1±7.9	81.6±14.9	81.8±17.1	1	53.203	<.001*	.155	2	2.75
	Peak velocity time	2.2±3.5	1.3±0.8	2.2±3.1	1.3±1.9	1.2±1.1	1.3±2.1	1	7.564	.006*	.025	2	1.69
	Movement time	9.0±8.5	7.9±5.5	10.3±9.2	5.5±5.0	5.1±4.4	5.2±5.7	1	34.412	<.001*	.105	2	.863
Extension	Peak velocity	85.8±30.9	72.4±34.4	50.5±33.4	101.1±42.7	83.9±35.6	68.3±32.0	1	8.835	.003*	.030	2	16.6
	Peak angle ratio	99.9±0.3	99.2±1.8	98.6±3.3	98.6±2.8	97.5±3.3	94.1±6.7	1	19.515	<.001*	.063	2	9.44
	Peak velocity time	3.8±3.1	4.6±3.3	5.4±4.6	2.8±1.9	3.4±2.4	4.4±3.5	1	18.241	<.001*	.059	2	5.80
	Movement time	9.0±4.5	10.7±6.5	13.2±7.6	7.0±5.0	7.6±4.5	8.5±5.8	1	31.071	<.001*	.097	2	5.20

In ANCOVA, gender was used as a covariance for correction. * $p < .05$.

Figures

Figure 1

The SAMO, therapeutic arm motion evaluation and training system. (a) Actuator units and control drivers. (b) Display and application for controller with data correction. (c) The robotic is a right-hand unit. This photo is an overview of SAMO. This equipment was produced by authors and this photo is created completely original.

Figure 2

Therapist and student therapeutic motion data collection protocol. Gray and white boxes indicate time progression in tasks and intervals. The subject's task involved the flexing of the elbow joint from the maximum extension position to the maximum flexion position, and back to the maximum extension position. Each subject performed nine tasks. The posture, grip position, holding method, and task execution speed were unspecified. Subjects were instructed to perform the therapeutic motion therapy suited to the muscle tone of the SAMO. *The severity of muscle hypertonia (mild, moderate, severe) was randomly set using the robot settings. These photos are completely original. Written informed consent was obtained for publication by the subject in photos.

Figure 3

Representative examples of the therapeutic motion techniques of four therapists and four students. (a) Variation in standard elbow joint angle rate during therapeutic motion therapy. (b) Variation in velocity during therapeutic motion therapy. The standard elbow joint angle rate was normalized by dividing the angle obtained during task performance by the maximum angle obtained from SAMO. The standard time was normalized by movement time during task performance. The black circles are used to plot the standard elbow joint angle rate of therapists. The gray triangles are used to plot the standard elbow joint angle rate of students. The solid black line shows the regression curve for the therapists. The solid gray line shows the regression curve for the students.

Figure 4

Comparison of therapeutic motion techniques based on subject and degree of muscle tone. (a) Peak flexion velocity, (b) Peak flexion angle ratio, (c) Peak flexion velocity time, (d) Flexion movement time, (e) Peak extension velocity, (f) Peak extension angle ratio, (g) Peak extension velocity time, (h) Extension movement time. Blue circles; therapists (n = 8), yellow circles; students (n = 25). Therapists vs students; *p < .05. Within group comparison; †p < .05.