MYU Tokyo

S & M 3632

Effectiveness and Usability of Hand–Wrist Stretching Device for Spasticity in Chronic Hemiparetic Stroke Patients

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(Received October 23, 2023; accepted March 22, 2024)

Keywords: spasticity, stroke, stretching, hand, hemiparetic

Stretching is a widely used method for managing spasticity. It involves elongating muscles and soft tissues to improve flexibility and range of motion. We aimed to evaluate the effectiveness and usability of static stretching utilizing a Hand–Wrist Stretching Device (HWSD) that we developed for managing spasticity and improving the motor function in individuals with chronic post-stroke hemiparesis. A repeated experiment was conducted to assess the effectiveness and usability of the HWSD. The HWSD includes a forearm holder, a frame, a finger holder, adjustable hinges, straps, and thumb stretchers. The Modified Ashworth Scale (MAS), the Box and Block Test (BBT), and a subjective usability questionnaire were used for evaluation. The results of applying the MAS revealed a significant difference with time and stretching angle for the elbow ($p < 0.05$). Both the elbow and wrist showed a significant decrease in MAS scores, and the BBT results demonstrated a significant improvement after stretching ($p < 0.05$). The subjective perception ratings consistently remained above 4.0. The HWSD effectively relieves hand spasticity and improves hand mobility in chronic stroke patients. Subjective perception ratings were positive. In future studies, the application of HWSD to patients with various forms of spasticity can be explored and its long-term effects investigated.

1. Introduction

Spasticity is defined as the velocity-dependent resistance of a muscle to stretching, and it is a common impairment that often occurs after a stroke.(1,2) The faster the muscle is stretched, the greater the resistance it exhibits.(3) This increased muscle resistance is often referred to as the tonic stretch reflex, which is generally regarded as a pathological reflex owing to its association with abnormal muscle overactivity. Additionally, spasticity is associated with pain and joint contracture, which can lead to functional loss, diminished quality of life, and an increased

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https://doi.org/10.18494/SAM4793

burden on caregivers.[4–7] Hence, proper intervention for spasticity is crucial in the rehabilitation of stroke patients.

Multiple treatment methods are available for managing spasticity in stroke patients, including physical therapy, pharmacological interventions, electrical stimulation, surgical procedures, and other complementary approaches.[2,4,8–12] However, stretching is a commonly employed technique in the physical management of spasticity. It involves elongating the muscles and soft tissues to alleviate muscle tightness, improve flexibility, and expand the range of motion in individuals with spasticity. Manual stretching closely resembles clinical practice, but it is labor-intensive and challenging to standardize. In contrast, mechanical stretching provides well-controlled interventions. However, most mechanical upper-limb stretching devices are expensive, large, and complicated, which makes them less easily applicable for personal use.[13–16]

As mentioned above, the development of mechanical upper limb stretching devices for stretching purposes and research on the effects and usability of these devices on spasticity and motor function are beneficial for individuals with spasticity following a stroke. Therefore, in this study, we investigated the effectiveness and usability of static stretching utilizing the hand–wrist stretching device (HWSD) that we designed and developed, on spasticity and motor function in individuals with chronic hemiparesis following a stroke.

2. Materials and Methods

2.1 Subjects

Twenty-eight patients [22 males, six females; mean age = 57.06 (±11.50) years, ranging from 37 to 72] were recruited from the occupational therapy room of Chung Shan Medical University Hospital (CSMUH). The patients were recruited on the basis of the following inclusion criteria: (1) more than six months after stroke onset; (2) age between 20 to 75 years; (3) wrist and elbow flexor spasticity [Modified Ashworth Scale (MAS) score of ≥1]; (4) no history of any invasive procedures (such as Botox, alcohol, or phenol) for the treatment of spasticity for at least three months before the start of the study; and (5) no cognitive problems (Mini-Mental State Examination score of >25). Institutional review board approval of the study was granted by the China Medical University Hospital Research Ethics Committee (protocol number RREC-110-021), and all the participants provided written informed consent.

2.2 Stretching device

The HWSD consists of a forearm holder, a frame, a finger holder, two adjustable angle hinges, four adjustable straps, and two adjustable thumb stretchers (refer to Fig. 1). The frame and holders are made of wood, the hinges are made of metal, and the straps and stretchers are made of polyester. The forearm holder is securely attached to the frame. The finger holder, designed to accommodate the four fingers (from the 2nd to the 5th digits), is connected to adjustable angle hinges for wrist extension. One end of the hinge is fixed to the forearm holder, while the other end is fixed to the finger holder. The frame also includes an adjustable hinge for

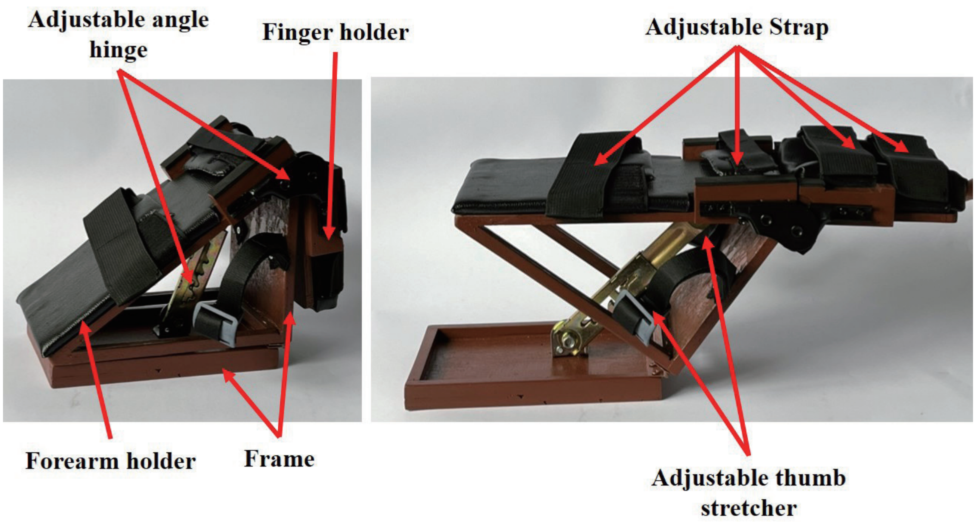

Fig. 1. (Color online) The Hand–Wrist Stretching Device (HWSD).

elbow flexion. The adjustable angles for wrist joint extension are 35° and 55°, while the angles for elbow flexion are 0° and 150°. Both the forearm and finger holders feature a foam cushion on top. The lengths of the adjustable straps can be modified to maintain the subject's forearm and palm positions and accommodate their hand size. Additionally, the adjustable thumb stretcher, which includes a thumb-hold ring and string, is positioned on both sides of the frame.

2.3 Experimental design

A repeated experimental design was employed to examine the effects of different stretching angles of the HWSD on spasticity and motor function in individuals with hypertonia following a stroke. Four stretching angles were tested: (1) 35° of wrist extension with 0° of elbow flexion (SA1), (2) 55° of wrist extension with 0° of elbow flexion (SA2), (3) 35° of wrist extension with 150° of elbow flexion (SA3), and (4) 55° of wrist extension with 150° of elbow flexion (SA4). The order of the four conditions was randomly assigned and counterbalanced among participants. The objective of the tests was to assess the efficacy of HWSD in reducing spasticity, and to evaluate its impact on functional activities and gauge the participants' perception of its usability.

2.4 Clinical and usability evaluation

Modified Ashworth Scale: The MAS was utilized to assess the severity of spasticity in the flexor muscles of the wrist and elbow joints. It is a 6-point numerical scale that assigns grades of spasticity ranging from 0 to 4 (0, 1, 1+, 2, 3, and 4), where 0 indicates no resistance and 4 represents a limb rigid in flexion or extension.[17,18] Categories 1 to 4 of the MAS were revised to include a range of 1 to 5 for the purpose of statistical analysis. The MAS evaluation was conducted by the physician prior to initiating stretching (pre-stretching) and after each stretching session (post-stretching).

Box and Block Test (BBT): The BBT was employed in this study to measure gross manual dexterity.[19] It is a widely used and well-developed assessment method known for its good inter-rater and test-retest reliability.[20,21] The test was performed following the standard BBT protocol. Participants were instructed to transfer one block at a time from one box to another using their affected hand within a 60 s time frame. The BBT was conducted before starting the stretching (pre-stretching) and after each stretching session (post-stretching), and the number of blocks moved was recorded for further analysis.

Usability Questionnaire. Usability aids product evaluation and user-centered design by gathering patient feedback for improving products to meet user needs. The usability of HWSD was assessed using the Assistive Technology Usability Questionnaire, which consists of 10 scale items, including effectiveness, comfort, adaptability, ease of putting on/off, and safety.[22] The scale items were collected after completing all experimental conditions using a five-point Likert-type rating scale: (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree.

2.5 Experimental procedure

The experimental procedure consisted of preparation and testing stages. In the preparation stage, participants were provided with an explanation of the experimental objectives and procedures before the start of the experiment. Basic information was collected, and participants provided their consent. To establish a baseline, the initial evaluation was conducted using the MAS and the BBT. In the testing stage, participants placed their affected hand on the forearm holder and inserted their fingers (from the 2nd to the 5th digits) into the finger holder and adjustable thumb stretcher. Velcro straps were used to secure the affected upper limb at two points: the forearm and the proximal portion of the second to fifth fingers. The researcher adjusted the straps tightly on the finger holder and fully stretched all the fingers by pulling the string of the adjustable thumb stretcher. Each participant performed the task under four experimental conditions, as illustrated in Fig. 2. Under each of the four experimental conditions, participants engaged in a 5-min stretching session, followed by a 3 min resting period. After completing the tasks under each experimental condition, the MAS was evaluated, and the BBT was performed. Upon completing the tasks under all experimental conditions, each participant was asked to complete a subjective usability questionnaire. In the event that a participant is unable to complete the questionnaire because their dominant hand has been affected, the researcher will record their feedback and complete the questionnaire on their behalf.

2.6 Statistical analysis

We used SPSS 22.0 for the data analysis. The one-way repeated measures analysis of variance (ANOVA) was employed, with the time (pre- and post-stretching) and stretching angle (SA1, SA2, SA3, SA4) as the within factors. The Bonferroni correction was performed as a post hoc test. The significance level for the p-value was set at 0.05.

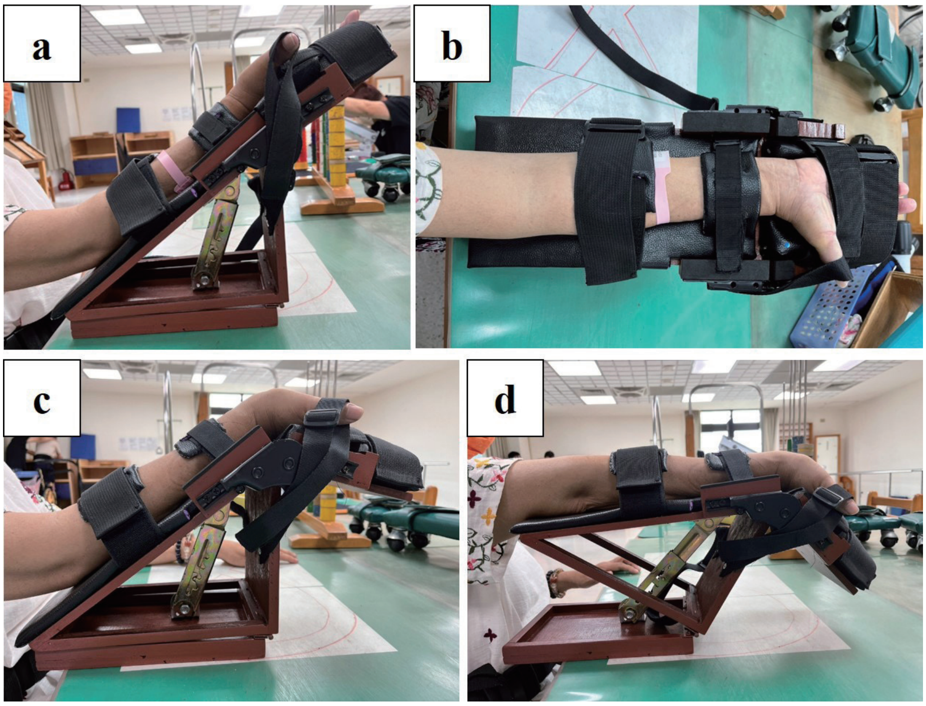

Fig. 2. (Color online) Stretching the affected hand using the stretching device. (a) Set the affected hand on the stretching device (lateral view). (b) Set the affected hand on the stretching device (top view). (c) Stretch the affected hand with a 35° wrist extension and 150° elbow flexion (SA1). (d) Stretch the affected hand with a 35° wrist extension and 0° elbow flexion (SA3).

3. Results

Demographic and baseline clinical data for the participants are shown in Table 1. The affected hand of the 18 participants corresponds to their dominant hand. The baseline range for the MAS assessment of both the participants' elbow and wrist flexor was 1 to 4 (adjusted to 1 to 5 for statistical analysis).

The one-way repeated measures ANOVA test of the MAS results for the elbow flexor muscles revealed a significant difference with time and stretching angle ($p < 0.05$). The post hoc test indicated that after stretching, the mean MAS scores were lower at SA1 and SA2 than at SA3 and SA4 ($p < 0.05$) (see Fig. 3). Additionally, significant effects of pre- and post-stretching were observed for both the elbow flexor ($p < 0.05$) and wrist flexor ($p < 0.05$) (Table 2). The MAS scores of the elbow and wrist were lower after stretching than before stretching (see Fig. 3).

The one-way repeated measures ANOVA test for the BBT results indicated no significant difference in time and stretching angle ($p > 0.05$). However, the results showed statistically significant effects pre- and post-stretching ($p < 0.05$; see Table 2). The number of blocks picked up after stretching was significantly higher than before stretching at four different stretching angles (see Fig. 3).

Table 1
Baseline demographic of participants.

	Age	Gender, *n* (%)		Affected side, *n* (%)		Duration	MAS (elbow), *n* (%)		MAS (wrist), *n* (%)	
	(yrs)	Male	Female	Right	Left	(yrs)	1, 1^+	2, 3, 4	1, 1^+	2, 3, 4
All (*n* = 28)	57.06 (11.50)	22 (79)	6 (21)	16 (57)	12 (43)	9.99 (14.19)	2 (7)	26 (93)	13 (46)	15 (54)

Note: data are expressed as mean value and standard deviation (SD) and as a percentage for categorical and binary variables.

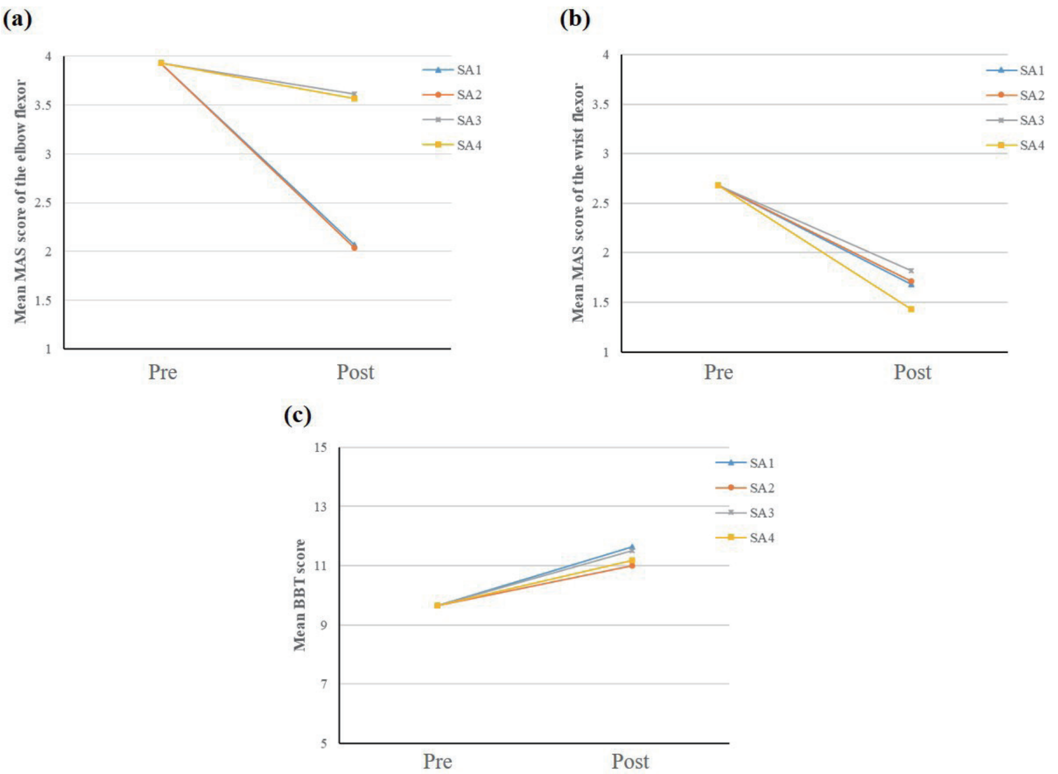

Fig. 3. (Color online) Change in MAS and BBT scores pre- and post-stretching at different stretching angles. (a) Mean MAS scores of elbow flexor muscles. (b) Mean MAS score of wrist flexor muscles. (c) Mean BBT score.

Table 2
Average pre-stretching and post-stretching MAS and BBT scores.

Clinical Measurement		Pre	Post	*p*-value
MAS	Elbow	3.93 (1.04)	2.82 (1.30)	< 0.000
	Wrist	2.68 (1.08)	1.66 (1.06)	< 0.000
BBT		9.64 (10.87)	11.33 (12.30)	< 0.000

Note: data are expressed as mean value and SD.

For the subjective usability assessment, the mean score of each item on the subjective comfort and usability scale was above 4.0. The three items with the highest mean scores were functionality/movement facilitation (4.68 ± 0.48), effectiveness (4.64 ± 0.49), and safety (4.57 ± 0.50). The item that had the lowest mean score was ease of putting on/off (4.04 ± 0.33). The following sample transcript presents the participants' additional responses regarding the assessment item of ease of putting on and off.

The fingers of my affected hand are severely contracted, and I am unable to straighten them even with assistance from my unaffected hand. (P5, P9, P14)

Because of severe stiffness in my affected hand, I am unable to independently straighten my fingers to secure them onto this hand–wrist stretching device. (P20)

Normally, I require assistance from a caregiver to straighten my fingers before putting on the hand orthosis. However, I am able to remove it myself. (P21)

4. Discussion

In this study, we investigated the effects of using a static stretching device at different angles of the wrist and elbow on spasticity and motor function in individuals with chronic hemiparetic stroke before and after stretching. Our findings indicated that extending the elbow joint to its maximum position and maintaining that position effectively reduced the spasticity of the affected elbow joints. Furthermore, we observed an improvement in the spasticity of the affected wrist and elbow joints after implementing static stretching exercises. Additionally, the motor function of the affected hand, as assessed using the BBT, demonstrated improvement after the stretching exercises.

Stretching is a commonly used physical management technique employed to reduce spasticity in chronic stroke patients. The primary objectives of stretching are pain relief, improved functionality, and enhanced flexibility of the flexor muscles and joint range of motion.[9,23] Stretching devices specifically designed to target spasticity in the hand and wrist have been investigated in several studies, and the effectiveness of such devices in reducing spasticity, as evidenced by before-and-after stretching assessments, has been reported.[24–27] Additionally, extending and maintaining the elbow joint at its maximum position induce stress relaxation in the muscles and tissues of the arm.[28] Nevertheless, the effects of stretching the wrist and elbow at different angles on hand spasticity and motor function were not considered in previous studies.

The assessment of usability using a user-centered design approach plays a crucial role in evaluating products during their development. By gathering patients' opinions about the product, it becomes possible to create improved products that align more effectively with their specific needs and requirements.[29,30,31] The results of our study demonstrated that the HWSD not only has stretching functionalities that effectively reduce hand spasticity and enhance hand motor function, but it is also considered safe for use. However, because of the severe constriction of the patient's affected hand resulting from spasticity, they require assistance from others to use the HWSD. Therefore, the perspective of caregivers was crucial in the design and development of the rehabilitation device.[32–34]

Robotic rehabilitation devices offer numerous advantages and are a growing trend. The benefits of a robotic rehabilitation device include more intensive therapy sessions, automatic feedback mechanisms, reduced therapy hours, and customization of patient-specific therapy, among other advantages.(35) However, current robotic rehabilitation devices still lack clinical evidence regarding material usage and usability.(36,37) Therefore, more work needs to be done to improve the design, comfort, safety, and implementation of these devices before their clinical trials can be conducted.

5. Conclusions

In conclusion, we found that the HWSD effectively relieved hand spasticity and improved hand mobility in chronic stroke patients. Additionally, the ratings for subjective perception were positive. We believe that the HWSD would be beneficial in managing spasticity in patients with hemiplegic stroke. However, since we only examined the short-term effects of the HWSD, it would be valuable to explore its long-term effects in future research. Furthermore, the HWSD is currently a manual rehabilitation device. In the future, there is potential for further development of robotic hand–wrist stretching devices, followed by a more comprehensive validation of their effectiveness and usability.

Acknowledgments

This work was supported by National Science and Technology Council (NSTC) in Taiwan, under Grant 110-2221-E-029-022-.

References

1 J. W. Lance: Lancet **335** (1990) 606. https://doi.org/10.1016/0140-6736(90)90389-m
2 B. B. Bhakta: Br. Med. Bull. **56** (2000) 476. https://doi.org/10.1258/0007142001903111
3 J. W. Lance: Neurology **30** (1980) 1303. https://doi.org/10.1212/wnl.30.12.1303
4 D. K. Sommerfeld, U. Gripenstedt, and A. K. Welmer: Am. J. Phys. Med. Rehabil. **91** (2012) 814. https://doi.org/10.1097/PHM.0b013e31825f13a3
5 S. Pundik, A. D. Falchook, J. McCabee, L. Krisanne, and J. J. Daly: Stroke Res. Treat. (2014) 306325. https://doi.org/10.1155/2014/306325
6 A. K. Welmer, M. Arbin, L. W. Holmqvist, and D. K. Sommerfeld: Cerebrovasc. Dis. **21** (2006) 247. https://doi.org/10.1159/000091222
7 Q. V. Doan, A. Brashear, P. J. Gillarde, S. F. Varon, A. M. Vandenburgh, C. C. Turkel, and E. P. Elovic: PM R. **4** (2012) 4. https://doi.org/10.1016/j.pmrj.2011.10.001
8 A. P. Salazar, C. Pinto, J. Mossi, B. Figueiro, J. L. Lukrafka, and A. S. Pagnussat: Ann. Phys. Rehabil. Med. **62** (2019) 274. https://doi.org/10.1016/j.rehab.2018.11.004
9 T. J. Bovend'Eerdt, M. Newman, K. Barker, H. Dawes, C. Minelli, and D. T. Wade: Arch. Phys. Med. Rehabil. **89** (2008) 1395. https://doi.org/10.1016/j.apmr.2008.02.015
10 N. Sahin, H. Ugurlu, and I. Albayrak: Disabil. Rehabil. **34** (2012) 151. https://doi.org/10.3109/09638288.2011.593679
11 A. Baricich, A. Picelli, A. Santamato, S. Carda, A. de Sire, N. Smania, C. Cisari, and M. Invernizzi: Clin. Drug Investig. **38** (2018) 991. https://doi.org/10.1007/s40261-018-0701-x
12 G. V. Tranchida and A. V. Heest: J. Hand Surg. Eur. **45** (2020) 34. https://doi.org/10.1177/1753193419878973
13 R. Kabir, M. Sunny, H. U. Ahmed, and M. H. Rahman: Micromachines (Basel) **13** (2022) 1033. https://doi.org/10.3390/mi13071033

14 Z. Qian and Z. Bi: Advances in Mechanical Engineering **7** (2014) 563062. https://doi.org/10.1155/2014/56306
15 E. Bardi, M. Gandolla, F. Braghin, F. Resta, A. L. G. Pedrocchi and E. Ambrosini: J. Neuroeng. Rehabil. **19** (2022) 87. https://doi.org/10.1186/s12984-022-01065-9
16 C. Liu, J. Lu, H. Yang, and K. Guo: Appl. Sci. **12** (2022) 4540. https://doi.org/10.3390/app12094540
17 R. W. Bohannon and M. B. Smith. I: Phys. Ther. **67** (1987) 206. https://doi.org/10.1093/ptj/67.2.206
18 A. D. Pandyan, G. R. Johnson, C. I. Priceet, R. H. Curless, M. P. Barnes, and H. Rodgers: Clin. Rehabil. **13** (1999) 373. https://doi.org/10.1191/026921599677595404
19 Y. J. Jung, J. H. Hong, H. G. Kwon, J. C. Song, C. Kim, S. Park, Y. K. Kim, S. H. Ahn, and S. H. Jang: NeuroRehabilitation **29** (2011) 53. https://doi.org/10.3233/NRE-2011-0677
20 J. G. Barry, S. A. Ross, and J. Woehrle: J. Neurol. Phys. Ther. **36** (2012) 17. https://doi.org/10.1097/NPT.0b013e318246203e
21 E. Elovic: Spsticity, A. Brashear and E. Elovic, Eds. (Springer Publishing Company, New York, 2015) 2nd ed., Chap. 5, pp. 49–72.
22 M. Masbernat-Almenara, F. Rubi-Carnacea, E. Opissoet, J. Medina-Casanovas, and F. Valenzuela-Pascual: PLoS One **18** (2023) e0281197. https://doi.org/10.1371/journal.pone.0281197
23 L. Gomez-Cuaresma, D. Lucena-Anton, G. Gonzalez-Medina, F. J. Martin-Vega, A. Galan-Mercant, and C. Luque-Moreno: J. Pers. Med. **11** (2021) 1074. https://doi.org/10.3390/jpm11111074
24 W. H. Jan, H. C. Kwon, K. J. Yoo, and S. H. Jang: Eur. J. Phys. Rehabil. Med. **52** (2016) 65. https://www.ncbi.nlm.nih.gov/pubmed/26086325
25 E. H. Kim, M. C. Chang, J. P. Seo, S. H. Jang, J. C. Song, and H. M. Jo: Ann. Rehabil. Med. **37** (2013) 235. https://doi.org/10.5535/arm.2013.37.2.235
26 K. M. Triandafilou, J. Ochoa, X. Kang, H. C Fischer, M. E. Stoykov, and D. G. Kamper: Top Stroke Rehabil. **18** (2011) 316. https://doi.org/10.1310/tsr1804-316
27 J. Kim, W. Park, and J. Kim: Sens. Mater. **32** (2020) 981. https://doi.org/10.3390/s22093368
28 S. Rao, M. Huang, S. G. Chung, and L. Q. Zhang: Front Neurol. **12** (2021) 742260. https://doi.org/10.3389/fneur.2021.742260
29 M. F. Penna, E. Trigili, L. Zollo, and C. Ciprianib: 18th Int. Conf. (ICCHP-AAATE, 2022) 420–427. https://doi.org/10.1007/978-3-031-08645-8_49
30 A. L. van Ommeren, L. C. Smulders, G. B. Prange-Lasonder, J. H. Buurke, P. H. Veltink, and J. S. Rietman: JMIR Rehabil. Assist. Technol. **5** (2018) e10510. https://doi.org/10.2196/10510
31 J. T. Meyer, R. Gassert, and O. Lambercy: J. Neuroeng. Rehabil. **18** (2021) 170. https://doi.org/10.1186/s12984-021-00963-8
32 C. M. Morrow, E. Johnson, K. N. Simpson, and N. J. Seo: IEEE Trans. Neural Syst. Rehabil. Eng. **29** (2021) 1213. https://doi.org/10.1109/TNSRE.2021.3090571
33 A. H. Spits, S. G. Rozevink, G. A. Balk, J M. Hijmans, and C. K. van der Sluis: Disabil. Rehabil. Assist. Technol. **22** (2022) 1. https://doi.org/10.1080/17483107.2022.2120641
34 C. E. Proulx, J. Higgins, and D. H. Gagnon: Disabil. Rehabil. Assist. Technol. **20** (2021) 1. https://doi.org/10.1080/17483107.2021.1938710
35 B. Brewer, S. McDowell, and L. Worthen-Chaudhari: Top Stroke Rehabil. **14** (2007) 22. https://doi.org/10.1310/tsr1406-22
36 N. W. Bartlett, V. Lyau, W. A. Raiford, D. Holland, J. B. Gafford, T. D. Ellis, and C. J. Walsh: J. Med. Device. **9** (2015) 030918. https://doi.org/10.1115/1.4030554
37 C. Y. Chu and R. M. Patterson: J. NeuroEng. Rehabil. **15** (2018) 9. https://doi.org/10.1186/s12984-018-0350-6

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