Assessment of Hand Rehabilitation after Hand Surgery by Means of a Sensory Glove

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Keywords: Sensory Glove, Hand Rehabilitation, Range of Motion (ROM).

Abstract: The assessment of hand functions after hand surgery treatment is essential to address the optimal rehabilitation procedures for any patient. To this aim, the current procedures anachronistically rely mainly on manual goniometers (highly prone to human errors) and know-how of experienced medical staffs (potentially prone to biased judgment), so that there is room for improvements in objective measurements of hand capabilities and new technological systems are very welcome. In particular, systems based on sensory glove are gaining more and more relevance in acquiring hand movement capabilities. Within this frame, in this research the Range of Motion (ROM) for all fingers and the ability of participants (health vs. patient subjects) to repeat two ADL (Activities of Daily Living)-based tasks were investigated. As a result, the glove-based system was evaluated in its feasibility for the assessment of hand function in clinical practice and rehabilitation settings.

1 INTRODUCTION

Hands are fundamental for human body beings in a huge number of tasks in our everyday life, for self-caring, acting, expressing, signing etc. (Chen et al., 2010). This is why, the correct measure of finger movements can be fundamental in assessing deficits after injuries of the central nervous system (Gentner and Classen, 2009), and/or in evaluating the outcome of hand surgery, so to dispense appropriate rehabilitation strategies in restoring patients' abilities (Borghetti et al., 2013).

Joint range of motion (ROM) measurement is one of the most important quantitative methods of hand-function evaluation (Dipietro et al., 2003). Mechanical goniometers or, more recently, potentiometric- and electro- goniometers are traditionally used to measure the passive ROM of each finger joint. The "small" dimension of finger segments, compared to the dimensions of the goniometers, makes difficult the simultaneous measure of the entire finger ROMs (Carpinella et al., 2006). Therefore, recently other techniques have been considered, based on optical technology, such as the analysis of digital photographic images (Vergara et al., 2003) and the multi-camera photogrammetry (Lee and Rim, 1991). These solutions represent improvements, but are limited only to static measurements. Dynamic and simultaneous measures are allowed by an optoelectronic analysis, but the necessary optical markers are prone to problems of occlusion, low ambient illumination can affect the result, and the high equipment cost do not favor their clinical acceptance.

Systems based on sensory glove can represent an interesting alternative within this frame; this is why we intend to evaluate their feasibility (Saggio et al., 2014). Data recorded by means of a sensory glove can even furnish the possibility to drive an avatar of the hand, so to replicate the hand movements for further analysis (Saggio et al., 2009).

By means of a custom made sensory glove, we investigated all joint finger ROMs, and the ability of healthy and patient subjects to repeat gestures in performing two easy grasping tasks.

Saggio, G., Sbernini, L., Leo, A., Awaid, M., Lorenzo, N. and Gaspari, A.
Assessment of Hand Rehabilitation after Hand Surgery by Means of a Sensory Glove.
DOI: 10.5220/0005704201870194
In *Proceedings of the 9th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2016) - Volume 1: BIODEVICES*, pages 187-194
ISBN: 978-989-758-170-0

2 MATERIALS AND METHODS

2.1 Sensory Glove

Typically, a sensory glove is a cloth glove equipped with flex sensors (Saggio, 2012). It was proposed for semi-automated goniometry in order to address the shortcomings of passive measures and to explore functional activities (Dipietro et al., 2003; Williams et al., 2000). Different types of sensory glove have been proposed, both commercial and research ones.

To best fit our requirements, we developed two twin indigenously-made sensory gloves (small and medium sized), equipped with 14 resistive flex sensors (by Flexpoint Sensor Systems, Inc., Draper, UT) placed in correspondence of the interphalangeal (IP) and metacarpophalangeal (MCP) joints of the thumb, and distal interphalangeal (DIP), proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joints, to trace finger flex/extension movements (see Figure 1). When a sensor is bent, its resistance value increase proportionally to the bending angle (Saggio, in press).

Analog signals from the glove fed an ad-hoc realized electronic circuitry, which send processed data to a personal computer moving a hand avatar according to the measures.

2.2 Participants

A group of 11 subjects without hand abnormalities, 9 healthy (6 women and 3 men) averaging 26 years in age (range 24-32y) and 2 patients (2 women, 17 and 65y respectively), performed the tests. Patient #1 (17y) underwent left hand surgery after an incision injury for MCP joint of the index finger. Patient #2 (65y) underwent left hand surgery because of carpal tunnel syndrome and trigger finger (middle finger).

2.3 Experiment Set-up and Test Protocol

The experiment was divided into three tests termed A, B, C (detailed in the following), which requested to place the hand recursively in known positions, with the glove always kept.

Before each test, the subjects were asked to sit on a chair in front of a table, the arm and forearm forming 90°. The hand in flat position and the wrist in neutral position defined the reference for each of the joints at 0°.

The subject donned his/her best fitting sensory glove (medium or small size) above a latex one. He/she was then trained to the testing procedures, as

Figure 1: The sensory glove prototype and the experimental materials.

follows:

- **Test A** Open-Close: the subject placed his/her elbow joint on the table-top and was asked to completely open his/her hand (angle of 0°, without hyperextension) and then completely close it (the thumb above the fingers).
- **Test B** Grasping Bottle (*Transverse Volar Grip*): it started with the hand in flat position. The subject was asked to grasp (using all fingers), and to release a spray bottle (diameter 2.5cm, height 15cm, see Figure 1). He/she returned then to the initial neutral position.
- **Test C** Grasping Dressing Roll (*Five-Finger Pinch*): *Test C* was analogous to *Test B*, but a dressing roll (diameter 4.5cm, height 7cm) was used instead of the bottle.

The bottle and the roll grasps were adopted based on the most daily used hand-grips (Sollerman, 1995), and objects' neutral positions were drawn on the table-top. No time constraints were given during all the experiments.

For repeatability evaluation, the subjects performed each task five times without removing the glove. For reproducibility evaluation, the subjects performed again the overall procedure two weeks after (so that the glove was doffed and donned between days). For each repetition of each task, data of all sensors were acquired during the entire performance: from the starting position to the ending position of the hand.

Healthy subjects performed the tests by using both left and right hand; patients performed the tests only with the injured hand. During the two weeks between tests, patients followed a rehabilitation program (extracorporeal shockwave therapy), therefore data analysis can focus on the assessment of rehabilitation outcomes.

2.4 Data Processing

An ad-hoc circuitry was designed to acquire data from sensors and to condition the signals (resistance values were converted into voltages and analog values into digital ones), before transmitting them to a personal computer, which converted incoming data into original angles for further analysis.

Test A: Angle data was processed obtaining the average ROM (maximum angle – minimum angle) for each finger joints. Repeatability of the measures was assessed considering standard deviation (SD) values.

Test B and *C*: The repeatability among dynamic measures was assessed considering the intra-class correlation coefficient (ICC) (Shrout and Fleiss, 1979), close to 1 for a high reliability, close to 0 for low reliability. For each measure, the dynamic angle values were time-normalized, so to calculate the ICC coefficients comparing curves with the same number of samples.

2.5 Statistical Analysis

For each day and for each healthy subject, we obtained a reference value of the entire hand for the two parameters of repeatability, SD of ROM (*Test A*) and ICC coefficient (*Test B* and *C*). We calculated the mean value across all finger joints and a statistical analysis was performed using these results. An ANOVA for repeated measures with two within-subjects factors was conducted to assess if time and handedness (and their interaction) might influence measurements repeatability. The level of significance was set at 0.05.

2.6 User Interface

We developed a useful graphical user interface (GUI) to facilitate usability of our system by clinicians (Figure 2). The GUI allowed selecting the joint of interest that the clinician wants to evidence. Also, it allowed calculating the repeatability of each sensor/joint during dynamic tasks.

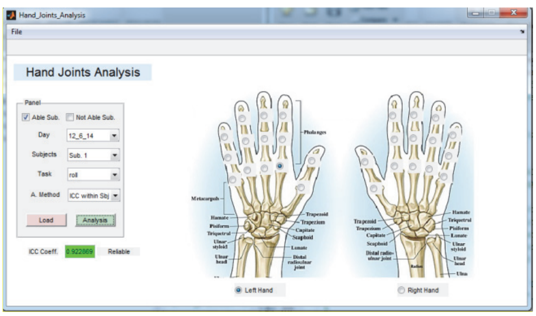

Figure 2: System Graphical User Interface (GUI).

All data processing was performed using Matlab (MATLAB R2013a, The MathWorks, Inc., Natick, MA) programs.

2.7 User Feedback Questionnaire

Feedback regarding comfort with handling and wearing the glove was assessed by a user questionnaire (Table 1) adapted from (Gentner and Classen, 2009; Simone, 2007). For each item, subjects were asked to select one of seven statements from 1 (strongly disagree) to 7 (strongly agree). Item Q12 was administered only to healthy subjects.

3 RESULTS AND DISCUSSIONS

3.1 *Test a*: Healthy Subjects

The mean ROM values and their SDs among all the healthy subjects are shown in Figure 3a,b separately for each joint. Repeatability of ROM is reported as standard deviation and all joints showed comparable SD values. SD for right hand range from 0.36° to 2.93° (mean value 1.60°) and from 0.92° to 8.49° (mean value 2.97°) for first and second day respectively; SD for left hand range from 0.66° to 9.84° (mean value 2.67°) and 1.35° to 5.96° (mean value 3.09°) for first and second day respectively.

3.2 *Test B* and *C*: Healthy Subjects

ICC analysis was performed for *Test B* and *Test C* individually, and for each sensor. For healthy subjects, the average values of ICC for each joint are shown in Figure 4a,b.

For *Test B*, the average ICC across all the fingers in the two days is 0.76 for the right hand and 0.79 for the left one. For *Test C*, the average ICC across all the fingers in the two days is 0.85 for the right hand and 0.83 for the left one.

The obtained ICC values were consistent with no particular joint showing markedly lower repeatability than the mean. Overall, repeatability was quantitatively assessed by ICC mean values ranging from 0.74 to 0.89 with a mean across joints of 0.81. These results were comparable to the ones obtained with the gloves evaluated by Simone et al. (Simone, 2007) (ICCs from 0.79 to 0.99 with a mean of 0.95), Dipietro et al., (2003) (ICCs from 0.7 to 1.0), and Mentzel et al., (, 2001) (ICCs from 0.82 to 0.99, with a mean of 0.94).

The repeatability and reliability of our sensory

Table 1: User feedback questionnaire*#.

Q#	*Question*
Q1	I felt comfortable as the glove was put on
Q2	I did not feel like my fingers were put into any uncomfortable position as the glove was put on
Q3	I felt any restriction to movement with this glove
Q4	I felt comfortable performing the activities in this study
Q5	The glove did not feel too tight (it did not make my hands or fingers tingle)
Q6	I feel like I can bend my fingers just like I can without wearing the glove
Q7	The glove did not feel too hot or too cold
Q8	I did not feel a reduction in tactile sensitivity of the fingers with this glove
Q9	I had no trouble during the grasping tasks wearing this glove
Q10	I did not feel like my fingers were put into any uncomfortable position as the glove was removed
Q11	I felt comfortable as the glove was removed
Q12	I did not felt any difference when I was worn the left glove

* Answers were coded as: 1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = neutral, 5 = somewhat agree, 6 = agree, and 7 = strongly agree.

[#] Adapted from (Gentner and Classen, 2009; Simone, 2007).

glove is similar to other evaluated gloves and also lies within the measurement reliability of manual goniometry. This result shows both the reliability of the used system and the ability of the healthy participants to repeat the same gesture. These results allowed us to use the system for further analyses with patient subjects.

3.3 Statistical Analysis

Statistical analysis showed that time and the interaction between time and handedness did not influence standard deviation of ROM values (respectively $p = 0.644$ and $p = 0.612$). On the contrary, there were significant differences ($p = 0.042$) comparing SD data between right and left hand.

For the dynamic repeatability of *Test B* and *Test C*, the statistical analysis was conducted across the ICC coefficients of the healthy subjects. It showed that time, handedness and their interaction did not influence repeatability of *Test B* (time $p = 0.868$; handedness $p = 0.295$; time*handedness $p = 0.234$). For *Test C*, the statistical analysis showed that time might influence dynamic repeatability of grasping a dressing roll ($p = 0.002$). On the contrary there were not significant differences due to the dominance of the hands ($p = 0.381$). The interaction between time and handedness did not present statistical differences ($p = 0.258$).

These results suggest that further investigations are welcome because of the two significance outcomes: handedness for the SD of the ROM ($p = 0.042 \approx 0.05$) and time for *Test C*. Grasping a dressing roll (*Test C*) might be a gesture not easy to repeat similarly between two days of measurements because even a healthy subject gets familiar with the gesture.

3.4 Feasibility Evaluation with Patient Subjects' Data

Patient subjects' results of the ROM (mean ± SD) (see Figure 3c,d individually for the two participants) demonstrate how the ROM has changed after two weeks of rehabilitation.

It is worth to investigate ROM results for the main joints involved in surgery. For patient #1 (left hand surgery after an incision injury for MCP joint of the index finger) values of the ROM of index joints markedly increase between days: MCP joint range 19.3÷77.3°; PIP joint range 53.1÷136.3°; DIP joint range 30.4÷63.9°. For patient #2 (middle finger joints surgery), values of the ROM of middle finger remain quite unchanged between days: MCP joint range 47.2÷48.3°; PIP joint range 32.3÷37.7°; DIP joint range 6.8÷9.6°. Patient subjects' outcome suggests that motor recovery for patient #1 was quicker than for patient #2. Actually, the former had easily recovered hand function abilities while the latter showed a slow recovery.

The average values of ICC of *Test B* and *Test C* for left hand joints of patient subjects are shown in Figure 4c,d. For *Test B*, the average ICC across all the fingers between days is 0.71 for the first patient and 0.56 for the second one. For *Test C*, the average ICC across all the fingers in the two days is 0.65 for the first patient and 0.82 for the second one. For the first patient, there was not an increase of the overall ICC values between the days of measurements, while there was a marked increment for the second patient. These results suggest

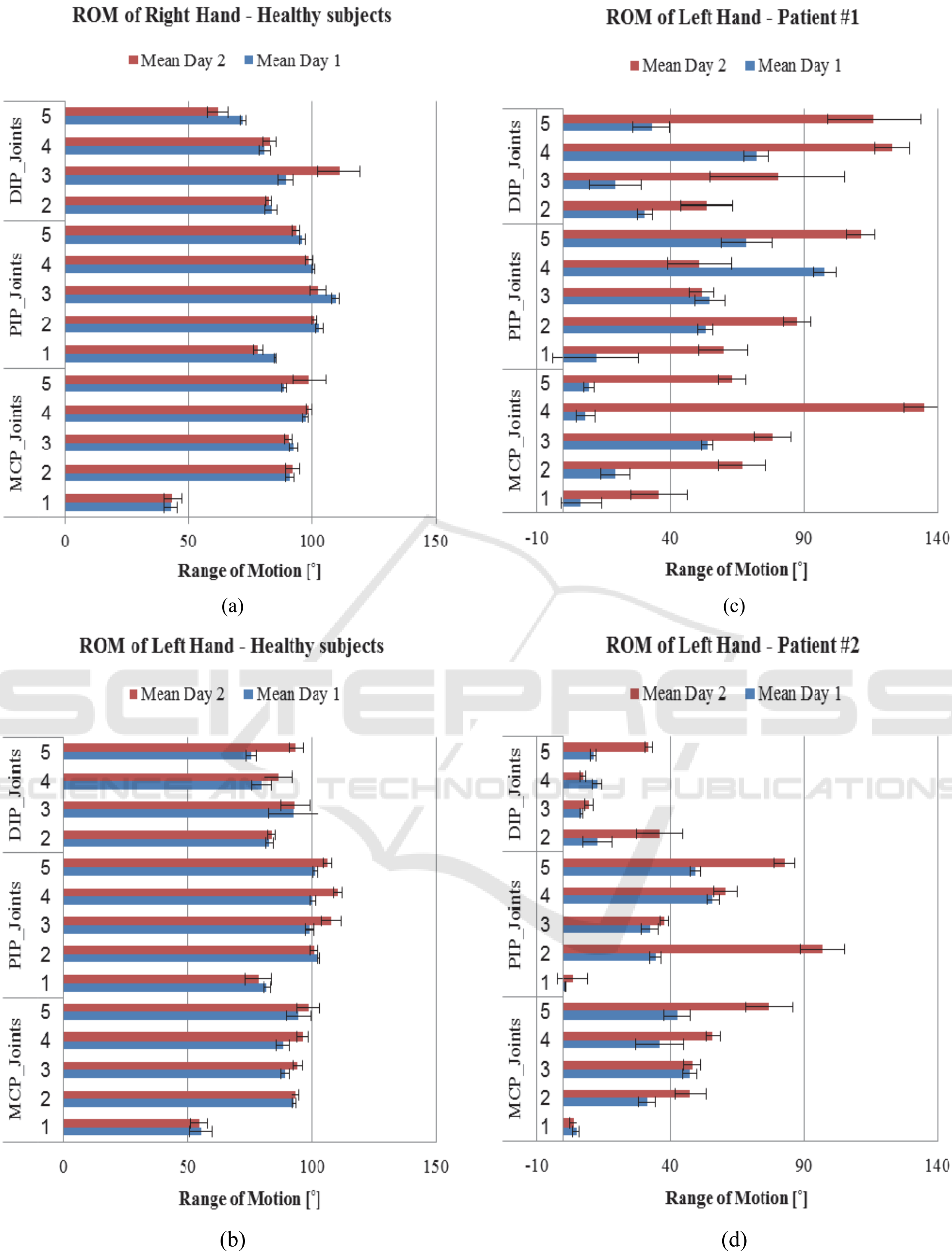

Figure 3: Range of Motion (ROM) values: for healthy subjects (a) right hand and (b) left hand; for patient subjects (c) Patient #1 and (d) Patient #2. Results are presented as mean value and standard deviation separately for each day of measurements. For each group of joints (MCP, PIP and DIP), fingers are coded as follows: 1 = thumb, 2 = index, 3 = middle, 4 = ring and 5 = small finger.

to assess specific tasks for different hand injuries.

Repeatability was quantitatively assessed by ICCs ranging from 0.64 to 0.74 with a mean across joints of 0.68 for the first patient, and ranging from 0.41 to 0.89 with a mean across joints of 0.69 for the second patient. Comparing with the results in Figure 4a,b, ICC values of patients are lower than the mean values of ICC of the healthy subjects as we expected.

3.5 User Feedback Questionnaire

The questionnaire gave positive responses to most questions: the average scores across all subjects are between 4.0 and 7.0 and between 5.0 and 7.0 out of a maximum score of 7 respectively for the first and second day (see Table 2). Average responses for all subjects were positive, the mean and SD being 5.82 ± 0.60 and 6.09 ± 0.28 for first and second day respectively. Responses were not significantly different between the healthy group and the patient group, so results are shown as average values across all subjects. Questions 1, 2, 10 and 11 addressed comfort during donning and doffing the glove and the average responses for all subjects were positive: 6.08 ± 0.25 and 6.12 ± 0.06 for the first and the second day respectively. Questions 3, 4, 5, 6, 7, 8, 9, and 12 captured feedback about the comfort performing the ADL-based activities wearing the glove and the positive average responses for all subjects reported a significant goal: 5.78 ± 0.43 and 6.07 ± 0.26 for first and second day respectively.

The average responses for all subjects for the second day is better than ones for the first day supposedly because of the subjects are being familiar with using the glove. From a general point of view the participants reported comfort with the glove and no relevant obstruction in movements.

4 CONCLUSIONS

The aim of this research was to furnish to the clinicians a system for measuring finger joints movement that is accurate, objective, easy to use and that delivers useful data through an easy user interface. It focused on the human finger postures and dynamic function movements during the accomplishment of ADL-based tasks rather than on the ability to accomplish these tasks. Furthermore, the proposed system allows tracking the movements of finger joints by means of virtual reality during a rehabilitation plane.

Our system is very easy to use, it can be used in many applications (e.g. evaluation of patient motor therapy and rehabilitation process), it can capture dynamically the full range of motion during finger-joint bending and it can monitor all the joints of one finger. Its performances are comparable to ones of other evaluated gloves, confirming the feasibility of the system, but to our knowledge, there are not other examples of applications of sensory gloves to assess hand surgery follow-up.

Table 2: User feedback questionnaire: mean scores per question.

	Healthy Subjects (N=9)		Patient Subjects (N=2)		All Subjects	
	Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
Q1	6.0	6.2	5.0	6.0	5.0	6.2
Q2	5.8	6.1	6.0	6.5	5.0	6.3
Q3	5.3	5.7	4.5	6.0	5.0	5.9
Q4	6.3	6.2	6.0	6.0	6.2	6.1
Q5	6.2	6.2	7.0	6.5	6.6	6.4
Q6	5.4	5.9	6.5	6.0	6.0	6.0
Q7	6.0	6.2	7.0	6.0	6.5	6.1
Q8	5.3	5.8	5.0	6.5	5.2	6.2
Q9	6.1	6.1	6.0	6.5	6.1	6.3
Q10	6.3	6.2	4.0	5.0	5.2	5.6
Q11	6.2	6.1	7.0	7.0	6.6	6.6
Q12	5.4	6.4	-	-	5.4	6.4
Total	5.9±0.4	6.1±0.2	5.8±1.1	5.7±1.9	5.7±0.7	6.2±0.3

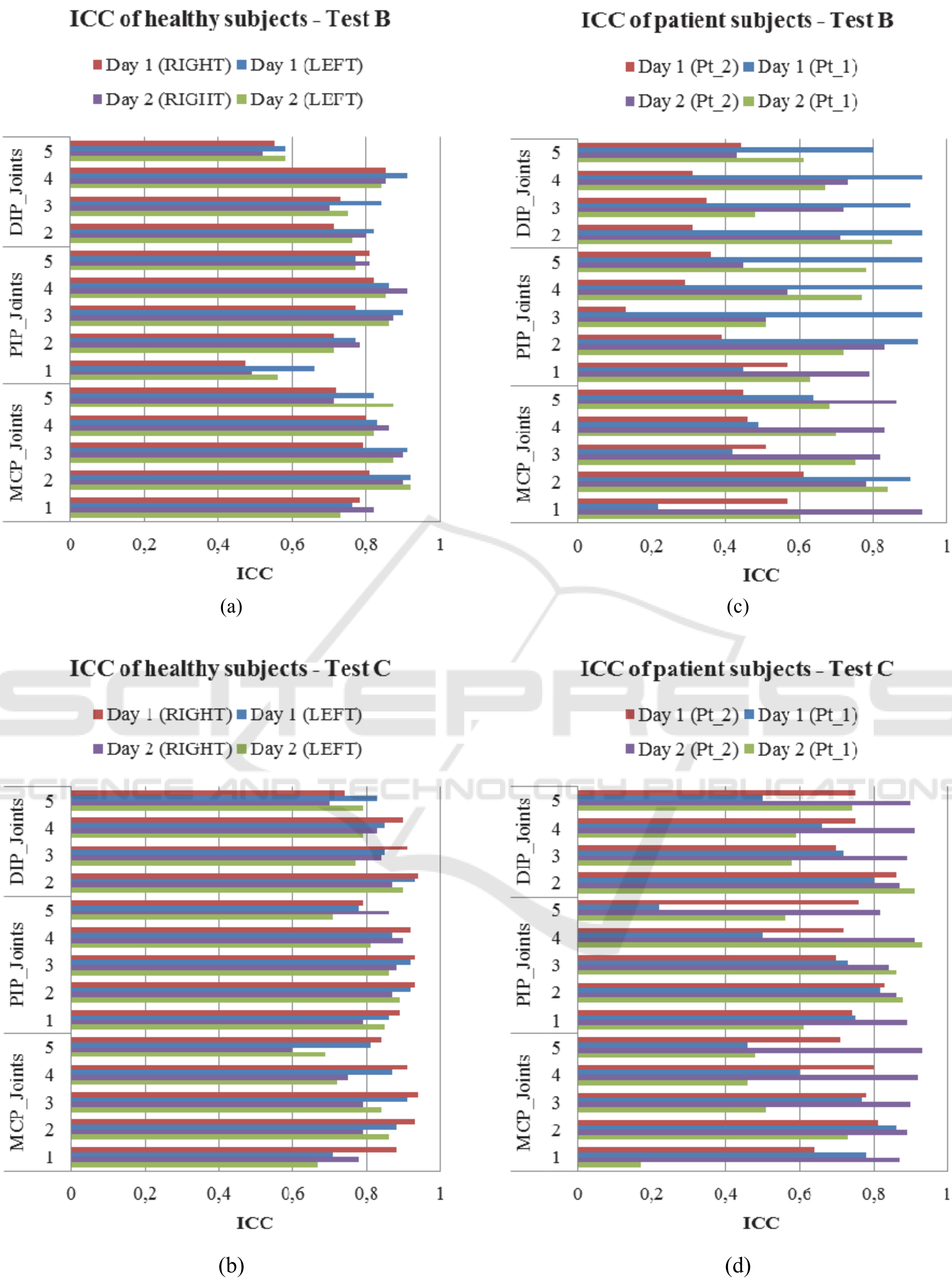

Figure 4: Mean values of Intra-class Correlation Coefficients (ICCs): healthy subjects Test B (a) and Test C (b); patient subjects Test B (c) and Test C (d). For healthy subjects results are shown separately for the right and the left hand. For each group of joints (MCP, PIP and DIP), fingers are coded as follows: 1 = thumb, 2 = index, 3 = middle, 4 = ring and 5 = small finger. Pt_1: patient subject #1; Pt_2: patient subject #2.

Through analyzing tasks of healthy subjects, we were able to study characteristics of the ROM of the finger joints and movement repeatability. The results of healthy subjects' tests might serve as standard values and help us in evaluating the severity of a hand functional deficit in the future.

This work presents the preliminary outcomes of our research, and its positive results encourage further studies aiming at confirming the present finding and fostering the proposed system into clinical practice. Our next steps will be to examine more patient subjects after hand surgery, to compare between them, to assess the rehabilitation process and correspondingly improve the efficiency of rehabilitation.

REFERENCES

Borghetti, M., Sardini, E., Serpelloni, M., 2013. Sensorized Glove for Measuring Hand Finger Flexion for Rehabilitation Purposes. *Transactions on Instrumentation and Measurement*. 62(12). p. 3308-3314.

Carpinella, I., Mazzoleni, P., Rabuffetti, M., Thorsen, R., Ferrarin, M., 2006. Experimental protocol for the kinematic analysis of the hand: Definition and repeatability. *Gait and Posture*. 23(4). p. 445-454.

Chen, H., Wang, Q., Cao, L., 2010. Design of the Workstation for Hand Rehabilitation Based on Data Glove. In *IEEE International Conference on Bioinformatics and Biomedicine Workshops*. p. 769-771.

Dipietro, L., Sabatini, A. M., Dario, P., 2003. Evaluation of an instrumented glove for hand movement acquisition. *Journal of Rehabilitation Research and Development*. 40(2). p. 179-190.

Gentner, R., Classen, J., 2009. Development and evaluation of a low-cost sensor glove for assessment of human finger movements in neurophysiological settings. *Journal of Neuroscience Methods*. 178(1). p. 138-147.

Lee, J. W., Rim, K., 1991. Measurement of finger joint angles and maximum finger forces during cylinder grip activity. *Journal of Biomedical Engineering*. 13(2). p. 152-162.

Mentzel, M., Hofmann, F., Ebinger, T., Jatzold, B., Kinzl, L., Wachter, N. J., 2001. Reproducibility of measuring the finger joint angle with a sensory glove. *Handchir Mikrochir Plast Chir*. 33(1). p. 59-63.

Saggio, G., Latessa G., De Santis, F., Bianchi, L., Quitadamo, LR., Marciani, MG., Giannini, F. 2009. Virtual reality implementation as a useful software tool for e-health applications. *1th IEEE International WoWMoM Workshop on Interdisciplinary Research on E-Health Services and Systems (IREHSS)*.

Saggio, G., 2012. Mechanical model of flex sensors used to sense finger movements. *Sensors and Actuators A: Physical*. 185. p. 53–58.

Saggio, G., Bizzarri, M. 2014. Feasibility of Teleoperations with Multi-Fingered Robotic Hand for Safe Extravehicular Manipulations. *Aerospace Science and Technology*. 39. p. 666-674.

Saggio, G., Riillo, F., Sbernini, L., Quitadamo, L. in press. Resistive Flex Sensors: a survey. *Smart Materials and Structures*.

Simone, L. K., Sundarrajan, N., Luo, X., Jia, Y., Kamper, D. G., 2007. A low cost instrumented glove for extended monitoring and functional hand assessment. *Journal of Neuroscience Methods*. 160(2). 335–348.

Shrout, P. E., Fleiss, J. L., 1979. Intraclass correlations: uses in assessing rater reliabiltiy. *Psychological Bulletin*. 86(2). p. 420-428.

Sollerman, C., Ejeskär, A., 1995. Sollerman hand function test: a standardised method and its use in tetraplegic patients. *Scand J Plast Reconstr Surg Hand Surg*. 29(2). p. 167-176.

Vergara, M., Sancho-Bru, J. L., Pérez-González, A., 2003. Description and validation of a non-invasive technique to measure the posture of all hand segments. *Journal of Biomechanical Engineering*. 125(6). p. 917-922.

Williams, N. W., Penrose, J. M. T., Caddy, C. M., Barnes, E., Hose, D. R., Harley, P., 2000. A goniometric glove for clinical hand assessment. Construction, calibration and validation. *Journal of Hand Surgery*. (European Volume) 25(2). p. 200–207.