Development and Evaluation of Tip Pinch Strength Measurement on a Paretic Hand Rehabilitation Device

Jung-Yeon Kim[1], Ye-Rin Cha[2], Sang-Heon Lee[2], and Bong-Keun Jung[2*]
[1]Department of Medical Science, Soonchunhyang University, Asan, South Korea
[e-mail: betterwithme@sch.ac.kr]
[2]Department of Occupational Therapy, Soonchunhyang University
Asan, South Korea
[e-mail: a31567633, sangheon, jungb@sch.ac.kr]
*Corresponding author: Bong-Keun Jung

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Abstract

In this study, we described the development of a methodology to measure tip-pinch strength on the paretic hand rehabilitation device and aimed to investigate reliability of the device. FSR sensors were embedded on the device, and tip pinch strength was estimated with data collected from the sensors using a developed equation while participants were demonstrating tip pinch. Reliability tests included inter-rater, test-retest, and inter-instrument reliability. B&L Engineering pinch gauge was utilized for the comparison. Thirty-seven healthy students participated in the experiment. Both inter-rater and test-retest reliability were excellent as Intraclass Correlation Coefficients (ICCs) were greater than 0.9 ($p<0.01$). There were no statistically significant differences in tip-pinch strengths. Inter-instrument reliability analysis confirmed good correlation between the two instruments ($r = 0.88$, $p < 0.01$). The findings of this study suggest that the two instruments are not interchangeable. However, the tip-pinch mechanism used in the paretic hand rehabilitation device is reliable that can be used to evaluate tip pinch strength in clinical environment and can provides a parameter that monitors changes in the hand functions.

Keywords: Robot-assisted rehabilitation, Upper extremity rehabilitation, Measurement of tip-pinch strength, Reliability, Wearable device

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1. Introduction

There is a growing concern over health in the world as populations are aging. More and more people suffer disability and death from chronic illness such as stroke and this was reported of a leading cause of death worldwide in 2010 [1, 2]. In addition, stroke is a leading cause of long-term disability due to neurological damage that quality of life of people with stroke is reduced as a limited distal motor function have negative impact on quality of life [3]. People with a form of disability are required to do rehabilitation exercise hoping for the recovery of their body functions through intensive rehabilitation exercises and repetition of the exercises [4]. Evidence suggests that the approach is beneficial to recover physical functions based on neural plasticity theory [5]. The theory argues that rehabilitation treatment through active or passive exercise, experience, and learning may accelerate recovery. It is further supported by other studies that task oriented exercise that is not simple activity have positive influences on reorganizing neural pathway [6, 7]. However, the fact that the availability of resources that can help stroke patients to recover upper extremity functions is limited further complicated problem. For example, stroke patients within 2 years of stoke occurrence at a hospital are able to have two sessions for rehabilitation treatment a day maximum by law and medical care support is reduced afterwards. In addition, most devices used in clinical settings are expensive for home use and they are too difficult to operate [8]. These advocate that ways or tools for self-managed rehabilitation exercise with ease of use at a low cost should be provided. A wearable device for paretic hand rehabilitation were developed in response to the needs [9]. Not only does the device provides a way to do self-managed rehabilitation exercise both at hospitals and home, but also it comes with a capacity to utilize force of each finger for playing a game. However, it was possible to implement a method to measure tip-pinch strength, which is an item of hand functions that are routinely checked to evaluate functional outcomes of stroke patients [10] since it equipped with FSR sensors. This study aimed to describe development of the method to measure tip-pinch strength and to investigate the reliability of the paretic hand rehabilitation device for measuring tip-pinch strength in healthy participants.

2. Related Work

2.1 Robot-Assisted Rehabilitation Exercise for Upper Limb

Increased availability of occupational or physical therapy can improve certain motor functions. However, not only the number of therapists, but also, the resources are limited. In order to tackle the problem, robot could be an answer to the problem. Providing interventions with robot-assisted exercise has been a frequently researched subject. We will discuss robot assisted rehabilitation system specific to upper limb due to the scope of this study. While a large number of robotic devices were developed, MIT-MANUS [11], Mirror Image Movement Enabler (MIME) [12], Bi-Manu-Track [13], and the Neuro-Rehabilitation-roBot (NeReBot) [14] were widely tested to evaluate efficacy of robot assisted device in terms of the delivery of rehabilitation treatment service. Patients with different stage of stroke, ranging from subacute to chronic, participated in Randomized Control Trials (RCTs) to compare the difference in functional outcomes of upper extremity and Activities of Daily Living (ADLs) between conventional intervention and robot-assisted exercise [12-18]. The findings of the studies suggest that early intervention with robotic training for upper limb could be a great help to improve ADLs in patients who received both robotic and conventional therapy. This was consistent in a review [19] that compared four-teen RCTs that examined the robotic device and it was reported that the robot-assisted exercise were similar or better effects on upper limb function whereas nine RCTs that assessed ADL reported similar or better effects were found in patients with hand motor function impairment. This was further supported by a Cochrane review [20] that significantly better improvement in upper limb function outcome evaluation were found when robot assisted arm training over traditional interventions was provided. To this end, currently available evidence suggests that robotic therapy, in addition to conventional therapy, helps to better improve upper limb motor functions. However, previous studies were limited to some extent in which they only focused to provide robotic training and did not explore another important aspect of rehabilitation that includes monitoring patients' engagement and evaluating functional outcomes.

2.2 Hand strength measurement

In rehabilitation, regaining pinch strength has been one of the most important functional outcomes to improve as it is a crucial ability that enables fine motor manipulative ADLs [21]. This has resulted in a significant number of studies conducted to develop normative standards for grip and pinch strength and it was studied in terms of many aspects that may cause difference in strength, such as age, region and gender [22-24]. The normative data is important because it determines the effectiveness of rehabilitation. In addition, it is required to set realistic goals for patients [22].

There are three types of pinch: lateral-pinch (also known as key pinch), palmar-pinch (also known as three-jaw chuck) and tip-pinch. Lateral-pinch is when a person grip with thumb pad and lateral aspect of index finger. When a person grips with their thumb, index and middle fingers, it is palmar pinch. Finally, tip-pinch grip is performed with thumb and index fingers. While most studies were completed in past decades, there are still related research conducted to develop normative standards for different aspects or to update [25, 26].

2.3 Pinch gauges

Hand functions are examined in clinical practice to measure functional outcomes [10]. Tip-pinch can be measured with an instrument called "Pinch gauge". Although there are several manufacturers such as B&L Engineering (B&L Engineering® pinch gauge), Fabrication Enterprises (Baseline®), and Asimow Engineering (JAMAR®), the purpose of pinch gauge is to measure hand strength, such as lateral, three-point and tip-pinch strength.

(a) (b) (c)

Fig. 1. B&L Engineering pinch gauge (a), Baseline pinch gauge (b), Baseline digital pinch gauge (c)

Fig. 1 shows the pinch gauges currently used in clinical settings and there are several research, such as development of normative standards or reliability and validity test, using the instruments [21-24, 27, 28]. Nevertheless, there was an issue reported that inconsistencies in reading and recording analog dial reading on pinch gauge were found since they are an analog type [29]. In response to the issue, a digital type of pinch gauge were developed and compared with an analog type [30] that reliability of the digital type were confirmed and used in research [31-33].

2.4 Paretic hand rehabilitation device

A concept design of a paretic hand rehabilitation device with a mobile application were proposed in [9]. The system focuses on providing users a guideline for self-managed rehabilitation exercise that requires the users' voluntary movement related to fingers and wrist.

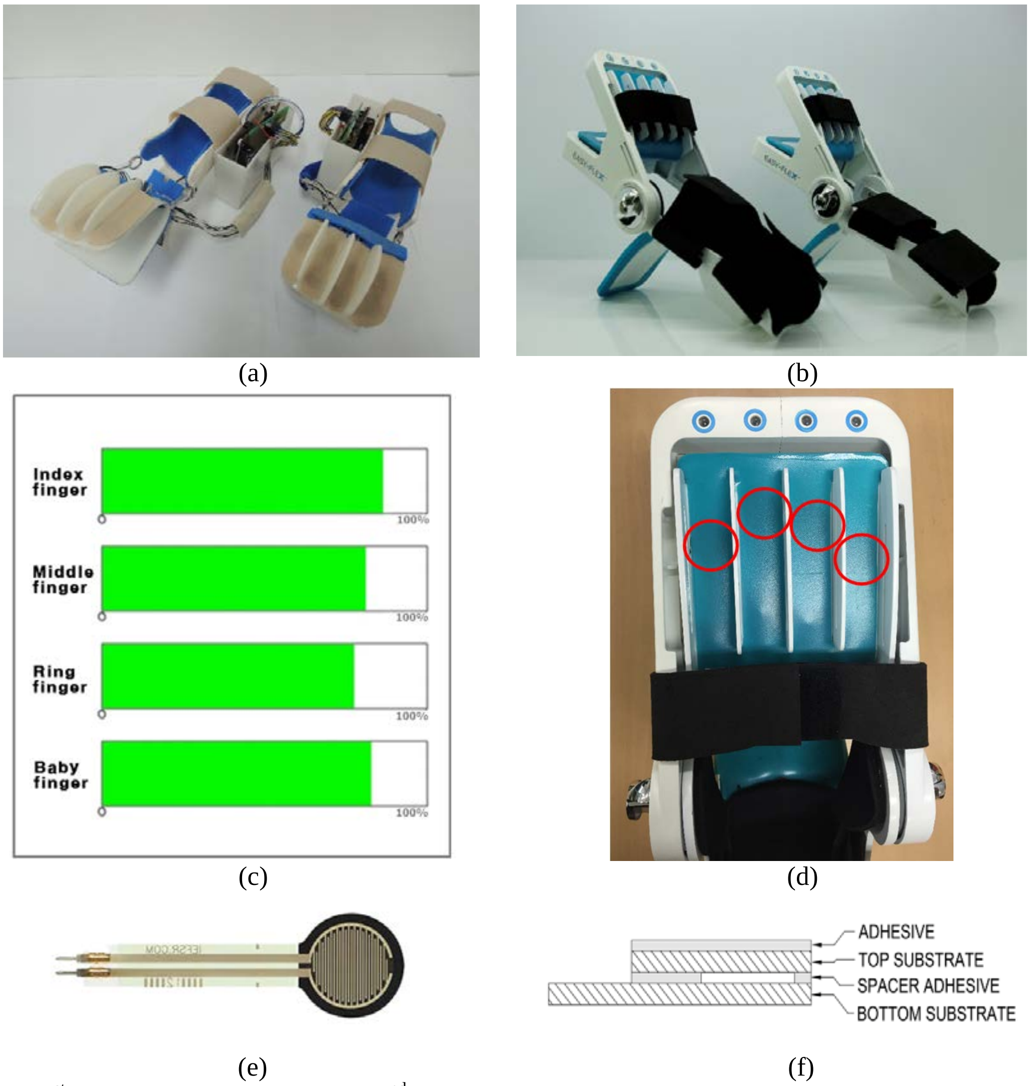
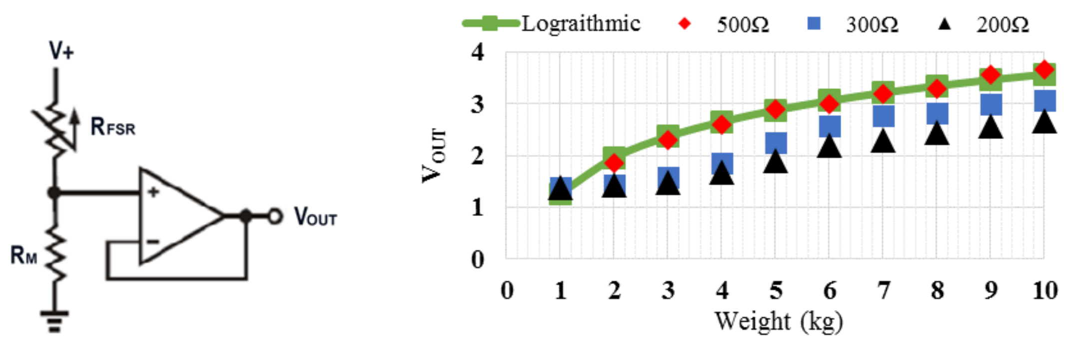


Fig. 2. 1st generation prototype (a) and 2nd generation prototype (b), bar graphs of the mobile application (c), locations of FSR sensors to detect pinch strengths of each finger on the paretic hand rehabilitation device (d), Interlink FSR 402 (e), and structure (f)

The 1st and 2nd generation prototype of the device can be seen in **Fig. 2(a)** and **(b)**. The device was initially designed to help patients with stroke to remain their closed hand opened and to provide ways of doing finger muscle contraction exercise. In addition, it also gives visual feedbacks in the way in which LEDs are turned on as long as the patients do the exercise with certain level of finger force as can be seen in **Fig. 2(c)**. This is possible because the system equipped with commercially available FSR sensors manufactured by Interlink (FSR 402) to detect force from individual fingers, except the thumb. **Fig. 2(d)** shows the plate of the device where fingers are rested on and FSR sensors were embedded on. [9] reported that 300 Ω and 3 V were originally applied for the proposed system.

3. Development

The initial version of the proposed device was modified to provide a function to measure tip-pinch strength. Although the manufacturer of the FSR sensors that were embedded in the proposed device provides the information on the sensor characteristics, we examined the behavior of the sensor to better understand behavior of the sensor in the proposed paretic hand rehabilitation device by recording voltage output based on the circuit where the output voltage increase as force rises. The voltage divider configuration can be found in **Fig. 3(a)**. While FSR resistance value was used as an input, an inverse voltage variation (from 0 V to V+) was used as an output (V_{OUT}). Three different measuring resistance (R_M) values (200, 300, 500 Ω) were applied to the FSR sensor with mass ranging from 1 to 10 kg. While 3.7 V was being supplied, the resistance multipliers were evaluated.



(a) (b)

Fig. 3. Voltage divider (a) and FSR voltage divider and estimated (b)

The test revealed that there was a curved relationship between weight and V_{OUT}, rather than a linear relationship (**Fig. 3(b)**). 500 Ω was selected as an R_M among the three different R_M values to derive a force estimation equation since it showed the best performance in terms of estimation. It was found that logarithmic model fitted to observed data with 0.988 of R square value ($p < 0.01$) resulting in the equation (1).

$$Vout = B0 + B1 \times \ln(m) \tag{1}$$

B0 and B1 were variables calculated with weight as independent value and Vout as dependent value and the values were 1.265 and 1 respectively in this application.

In the proposed system, 10-bit ADC was employed that ADC value changed within the range of 0 and 1023 while voltage reference was 3.7 V. When force was applied to the FSR sensor, ADC output changed, and the ADC output was converted to voltage using the equation below.

$$Vout = \frac{ADCreading \times Vreference}{ADCresolution} \tag{2}$$

Finally, weight was estimated using the equation (1) and (2) when each finger pressure was applied to FSR sensors in the proposed system.

4. Materials and Method

4.1 Instrument - B&L Engineering pinch gauge

Although there are a number of analog type of pinch gauges available, B&L Engineering pinch gauge (0 ~ 30 kg) (**Fig. 1(a)**) was used for comparison in this study because the highest accuracy among other instruments, such as Baseline and Jamar, was reported in [27]. The pinch gauge measures in 1 kg increment, and the red needle remains at maximum until reset.

4.2 Participants

Undergraduate students were invited for this study and thirty-nine students initially volunteered. However, two of them were excluded from the experiment as they had injuries in their hand in which they could not perform tip-pinch grip properly. Therefore, the total number of participants reduced to thirty-seven. No participants reported any injuries on their upper limbs during the experiments. Experiment protocol was approved by Soonchunhyang University Institutional Review Board and all participants provided their informed consent prior to experiment. Characteristics of participants are presented in **Table 1**.

Table 1. Characteristics of participants

Sex	**Number (%)**	**Age (years ± SD)**	**Total number (Right : Left)**
Female	28 (75.7%)	21.67 ± 1.34	28 : 0
Male	9 (24.3%)	25.75 ± 6.55	9: 0

SD: Standard Deviation

4.3 Raters

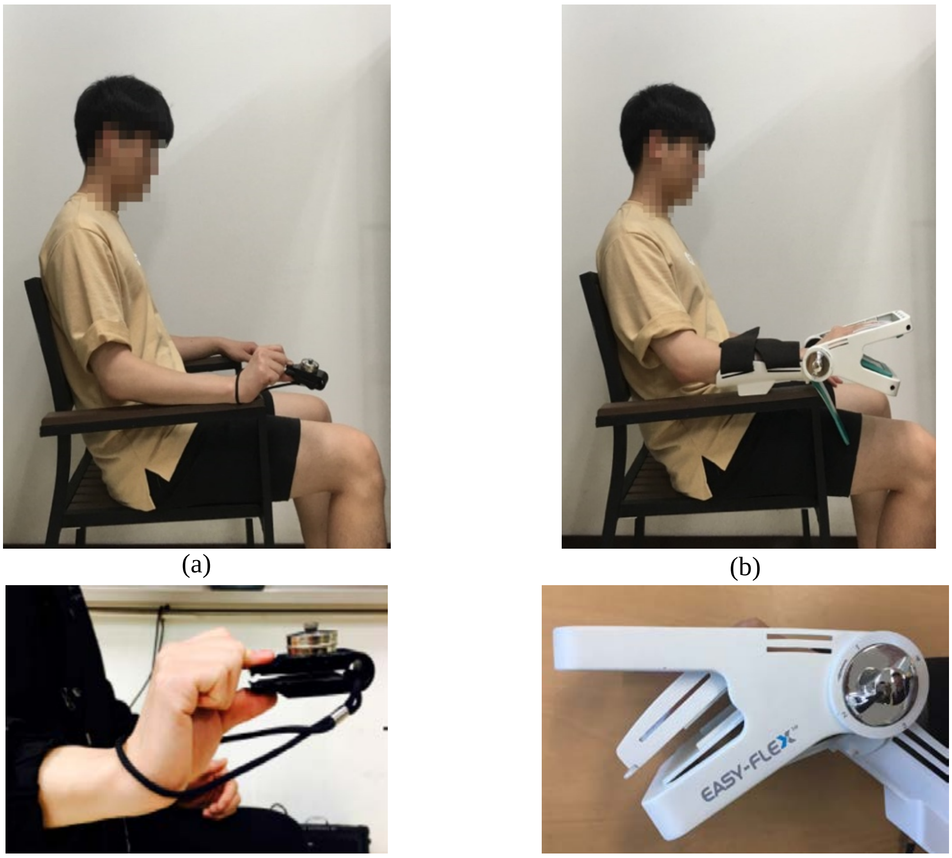
Two occupational therapists, experienced in tip-pinch measurement in clinical settings, were recruited for this study to perform all the evaluations. A brief session on how to use and administer tip-pinch strength evaluation with the paretic hand rehabilitation device was follwed by introduction of the device. They were blinded to the main purpose of this study.

4.4 Procedures

Data sets were collected on two separate evaluations. A review reported that comparison of measurements taken on two separate occasions (usually hours or days apart) were common to assess test-retest reliability in rehabilitation [34]. In addition, retest was completed 7 days after the first test while yielding high reliability [27, 35]. Therefore, second evaluation was carried out within a week in this study. Rater 1 administered tip-pinch strength measurement on a first evaluation with the paretic hand rehabilitation device and B&L Engineering pinch gauge. On a second evaluation, however, both rater 1 and rater 2 were involved with the measurement on a second evaluation, and the measurement was only completed with the digitized wearable device.

In order to minimize confounding factors, efforts were made to achieve the equal conditions for measuring tip-pinch strength regardless of instruments. First of all, since a standard for arm positioning when testing hand strength were recommended by American Society of Hand Therapists (ASHT) [36], the standard was employed for the experiment when measuring tip-pinch strength. The following information is a detailed explanation of the standard position for tip-pinch measurement. Participants were invited to (1) seat comfortably in a chair (45 cm) with arm rest, (2) have their shoulder abducted and rotated neutrally, (3) fix their elbows at 90º, (4) pronate their forearm, (5) and have wrist between 0º and 30º dorsiflexion, and between 0º and 15º of ulnar deviation. **Fig. 4(a)** and **(b)** show the standard position.

Once participants were properly positioned, they were requested to perform tip-pinch with either the B&L Engineering pinch gauge (**Fig. 4(c)**) or the plate of the hand exercise device (**Fig. 4(d)**). When the proposed system was used to measure tip-pinch, wrist part on the device was fixed to prevent wrist movement. The participants were asked to pinch for 3 to 5 seconds for each trial. 15 seconds between trials were given and three successive trials were recorded. Finally, at least 10-minute rest break was given to the participants between tests (performed with the other instrument or by the other rater). The order of the instruments were counter-balanced between the study participants.



(a) (b) (c) (d)

Fig. 4. Standard position for measuring tip-pinch strengths with instrument used in this study

4.5 Statistical Analysis

Inter-instrument, test-retest, inter-rater reliability were considered in this study. Inter-instrument, test-retest, and inter-rater reliability was investigated using paired t-test as well as Intraclass Correlation Coefficient (ICC) with 95% Confidence Intervals (CIs). Pearson's correlation coefficient was additionally calculated to evaluate repeated test scores within the rater as well as within the two different raters. The results were considered statistically significant when p value was less than 0.05 ($p < 0.05$). Scatter plots and Bland-Altman plots were presented to evaluate a bias between the mean differences in tip-pinch strength measured with the instruments and to estimate an agreement interval with 95% of differences between the instruments as proposed in [37]. SPSS 23.0 for Windows was used for statistical analyses.

5. Results

The B&L Engineering pinch gauge and the paretic hand rehabilitation device were used for measuring pinch strength of each participant. **Table 2** shows descriptive data on tip-pinch strengths for respective male and female participants.

Table 2. Descriptive data of tip-pinch depending on sex

Sex	Instrument	Mean (kg)	SD	SEM
Female	Paretic hand rehab device	3.53	± 0.42	0.08
	B&L Engineering pinch gauge	3.83	± 0.77	0.15
Male	Paretic hand rehab device	4.97	± 2.16	0.72
	B&L Engineering pinch gauge	4.96	± 1.62	0.54

SD: Standard Deviation, SEM: Standard Error of Mean

Mean tip-pinch scores of female participants measured with the proposed system and B&L pinch gauge were 3.53 (±0.42) and 3.83 (±0.77) respectively. On the other hand, tip-pinch strength of male participants taken with the two devices averaged 4.97 (±2.16) and 4.96 (±1.62). Results indicated that tip-pinch strength of male participants were greater than those of female regardless of the type of measurement instruments. **Table 3** presents inter-instrument reliability results. Tip-pinch measured by B&L pinch gauge is greater than the developed system by 0.2 approximately. Mean differences between B&L Engineering pinch gauge and the paretic hand rehabilitation device were 0.22 and were not statistically different ($t = 1.78$, $p = 0.058$) for total participants.

Table 3. Inter-instrument reliability (ICC)

Instrument	Mean (kg)	SD	SEM	Paired t-test (36)	ICC (95% CI)
Paretic hand rehab device	3.87	± 1.26	0.21	1.78	0.88* (0.76~0.94)
B&L Engineering pinch gauge	4.10	± 1.13	0.19		

SD: Standard Deviation, SEM: Standard Error of Mean *p < 0.01
ICC: Intraclass Correlation Coefficient, CI: Confidence Interval

The results (**Table 4**) indicates the excellent agreement between test and retest, and between raters. There were no statistical differences between tip-pinch strength of total participants at first and second evaluations ($t = 0.32$, $p > 0.05$). In addition, the scores at both evaluations were highly correlated with Pearson's' correlation coefficient $r = 0.98$ ($p < 0.01$). ICCs were also high with 0.99 ($p < 0.01$). In terms of inter-rater reliability, paired t-test revealed that differences between the measurements taken by each rater were not statistically significant (t = 0.39, p > 0.5). ICC was greater than 0.95 (p < 0.01) with 95% confidence interval demonstrating excellent inter-rater reliability.

Table 4. Test-retest reliability

Reliability		Mean (kg)	SD	SEM	Paired t-test (36)	Pearson's r	ICC (95% CI)
Test & Retest	1st	3.88	± 1.25	0.20	0.32	0.98*	0.99* (0.98~0.99)
	2nd	3.86	± 1.29	0.21			
Rater 1 & Rater 2	Rater 1	3.88	± 1.25	0.20	0.39	0.93*	0.98* (0.96~0.99)
	Rater 2	3.90	± 1.19	0.20			

SD: Standard Deviation, SEM: Standard Error of Mean *p < 0.01
ICC: Intraclass Correlation Coefficient, CI: Confidence Interval

Data sets of tip-pinch strengths were used for both scatterplots and Bland-Altman plots regardless of sex. **Fig. 5(a)**, **(b)**, **(c)**, and **(d)** show the relationships between tip-pinch strengths taken with the paretic hand rehabilitation device on the first and second evaluations, and between raters. There were strong linear relationships in both cases. Neither increase nor reduction in tip-pinch strength were found in both test-retest (**Fig. 5(b)**) and inter-rater reliability analysis (**Fig. 5(d)**) as the mean errors were close to zero. However, relationship were weaker and error margins were wider for the tip-pinch strengths measured by two different instruments as shown in **Fig. 5(e)** and **(f)**.

6. Discussion

It is important to confirm the reliability prior to use in clinical settings when developing new assessment instrument [38]. Therefore, inter-instrument, test-retest and inter-rater reliability were assessed and B&L Engineering pinch gauge was employed for evaluating inter-instrument.

Before commencing reliability tests, variables that may have influences on the study results were controlled. The B&L Engineering pinch gauge was selected because not only the highest accuracy was achieved among other pinch gauges, but also there were a large number of research that employed the pinch gauge for establishing normative data as well as testing reliability [27, 39-41]. In addition, a standard test position for hand strength was applied to prevent effects of different position of body, such as elbow and wrist, as previous studies suggest [42, 43] and this was widely used in related literature [22-24, 26, 27, 29, 32].

10 minutes rest between measurements were given to participants to avoid influences that were caused by multiple assessments. The amount of time for rest given to the participants between trials and between the instruments was found to be adequate to reduce the risk of fatigue [44]. In addition, sequence of instrument was randomized to minimize any order effect of the starting instrument as other related research reported that there was statistical difference in scores due to muscle fatigue from the particular order of the starting instrument [30].

Descriptive tip-pinch strength showed that tip-pinch strength of the dominant hand was stronger in male participants than female participants. This finding is consistent across related studies [22-24]. In addition, there were difference in overall tip-pinch strength measured by two instruments. A possible reason for this is measurment error might be due to incorrect reading of B&L Engineering pinch gauge or inproper operation of the analog scale [29]. This was observed when analog type of dynamometer and digital dynamometer were compared [14].

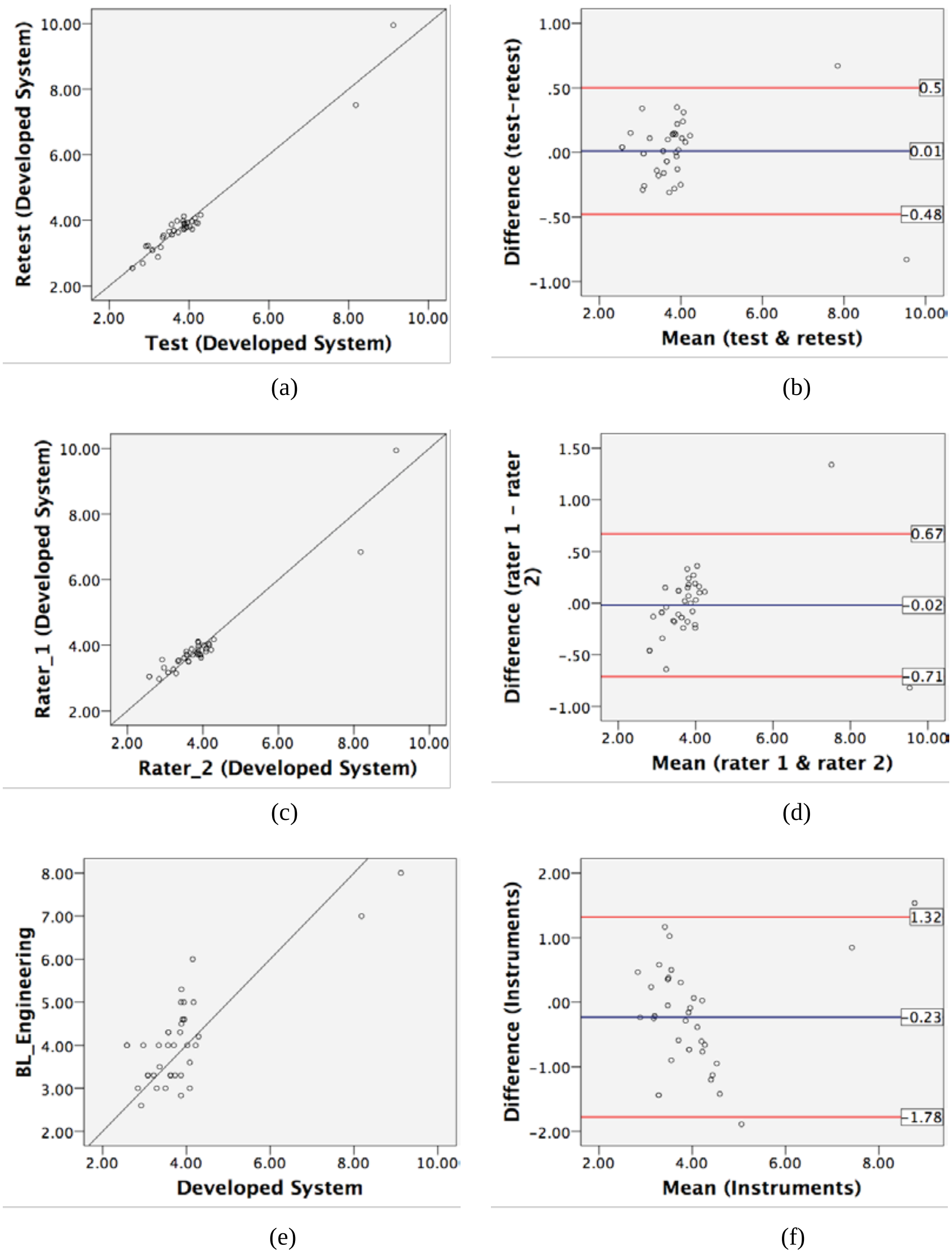


Fig. 5. Scatter plots for test-retest (a), inter-rater (c), and inter-instrument reliability (e), and Bland-Altman plots for test-retest (b), inter-rater (d), and inter-instrument reliability (f)

However, this study did not suffer the same limitation of the studies as the difference was not statistically significant.

In terms of reliability, test-retest, inter-rater, and inter-instrument reliability were examined. ICC was additionally computed to evaluate reliability as it was reported that ICC takes into account systematic error [45] and it was widely used to test reliability elsewhere [27, 29, 30, 40, 46]. The value of ICC can be interpreted according to [47] (poor: ~ 0.40; moderate: 0.40 ~ 0.75; high: 0.76 ~). ICC should be higher than 0.9 to be used in clinical practice as suggested in [48].

There were two outliers in the data, which can be seen in **Fig. 5(b)**, **(d)**, and **(f)**. They were investigated further and it was found that the outliers in **Fig. 5(b)** and **(d)** were caused by the same two participants whereas only of them was involved with the outliers seen in **Fig. 5(f)**. When the results of test-retest and inter-rater evaluations were investigated to address issues with the two extreme scores, it was revealed that tip-pinch strength measured at two different evaluations and between two different raters were consistent and correlated, which can be found in **Fig. 5(a)** and **(c)**. This was further investigated by comparing the actual values of the extreme cases. There were two people whose tip-pinch strength was approximately 9 and 8 kg at 1st and 2nd evaluations measured by rater 1. The measurements taken by rater 2 did not show considerable difference since they were close to 9 and 7 kg for the respective participants. In addition, their tip-pinch measurements evaluated with B&L Engineering pinch gauge was similar (8 and 7 respectively). The findings indicates that the two extreme scores in the two participants were consistent over time as well as between instruments. Although the extreme values of the two participants were found regular rather than being random, the two extreme values were excluded to re-examine reliability. Coefficients for test-retest and inter-rater reliability were recalculated, and paired t-test showed no significant mean differences between test-retest ($t = 0.605$, $p = 0.55$) and between raters ($t = 0.98$, $p = 0.33$). ICCs for test-retest and between raters were still greater than 0.90 with 0.96 ($p < 0.01$) and 0.91 ($p < 0.01$) respectively.

As stated earlier, two outliers found in **Fig. 5(f)** were not caused by the same participants. One of the two participants was common while a different participant was involved in case of inter-instrument reliability. The tip-pinch measurements of the new participant with the proposed method were consistent ranging from 4.05 to 4.15 kg. However, the mean difference of tip-pinch scores between the two devices was approximately 2 kg for the person. Mean differences and coefficients for inter-instrument reliability was re-examined excluding the two outliers. Paired t-test showed no significant difference between mean tip-pinch strength scores between the two instruments ($t = 1.80$, $p > 0.05$) while ICC was high (ICC = 0.81, $p < 0.01$).

High correlation and agreement between repeated measurements suggest that the paretic hand rehabilitation device is able to reliably measure tip-pinch strength over time. In addition, inter-rater reliability was high with ICCs being greater than 0.9. This indicates that when the participants are properly positioned as recommended by ASHT, raters with experience in measuring hand strength can independently assess the tip-pinch strength and obtain the same tip-pinch strength scores with the paretic hand rehabilitation device.

ICC estimated for investigating inter-instrument was excellent as the value was above 0.80. Nevertheless, the ICC was less than 0.90, which is considered having an acceptable level of inter-instrument reliability. This issue was found in [28] that pinch strengths measured with B&L Engineering pinch gauge and other pinch gauges, such as Baseline pinch gauge, were not equivalent. Therefore, the paretic hand rehabilitation device and B&L Engineering pinch gauge are not interchangeable.

Visual information employing scatterplots and Bland-Altman plots on tip-pinch strength were consistent with the results of statistical analyses. Relationship between test and retest, and between rater 1 and 2 were strong and systematic error was not found in comparison between two separate observations, and between raters. However, despite the fact that there was a statistically high correlation between B&L Engineering pinch gauge and the paretic hand rehabilitation device on tip-pinch strength, the relationship between the two instruments was rather weaker and instrument error between the two instruments were larger as seen in **Fig. 5(c)**. The graphical information supports statistical analysis that direct comparison of tip-pinch strength measured with each instrument is inadequate. This also suggests that normative data of tip-pinch strength collected with the B&L Engineering pinch gauge cannot be utilized to directly compare changes in tip-pinch strength measured with the paretic hand rehabilitation device.

Having established reliability of the paretic hand rehabilitation device for measuring tip-pinch strength enables patients with stroke to do self-managed rehabilitation exercises while they can also monitor their status of hand strength or other information, such as how long a user have been doing rehabilitant exercise. Moreover, the data can be remotely accessed since the information of the user are locally stored within the mobile application installed on smartphone where wireless communication is enabled. This is promising as the system is ready for tele-rehabilitation.

There are still limitations that need to be considered even though attempts to control possible confounding variables were made. The fact that the number of participants were thirty seven and their ages were ranging from 20 to 30 may be argued of being lack of representation of population. In addition, the balance of sex was not ensured although investigation according to sex was not the scope of this study. Finally, how the system behaves with the target users of the system remain unexplored. In addition, only B&L Engineering pinch gauge was used to measure tip-pinch strength for comparison while various types of gauge, including digital type. In fact, allowing more instruments for measuring tip-pinch and comparison between data measured by the instruments could help to better understand relationships between tip-pinch strength measured by clinical instruments and the proposed paretic hand rehabilitation device. Therefore, further investigations taking into accounts the limitation are expected.

7. Conclusion

The purpose of this study was to examine reliability of the paretic hand rehabilitation device in measuring tip-pinch strength. The findings of the studies suggest that the paretic hand rehabilitation device developed for self-managed rehabilitation exercise was found to be reliable in measuring tip-pinch strength overtime while the developed system is advantageous as the system could readily respond to the needs of tele-rehabilitation. However, the use of data collected with the paretic hand rehabilitation device is limited as B&L Engineering pinch gauge and the device do not equivalently measure tip-pinch strength. Further study is required to set normative data of tip-pinch with the paretic hand rehabilitation device and correlational analysis must be followed for data the device produces to be clinically important, and to discover how to utilize the data the proposed device produces in the delivery of rehabilitation service.

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Jung-Yeon Kim received MS degree in Mobile and Ubiquitous Computing from Lancaster University, Lancaster, the UK. He is now pursuing his Ph.D. in Medical Science at Soonchunhyang University. His current research interests include psychophysiological signal analysis, brain computer interface, mobile health, and ICT accessibility.

Ye-Rin Cha received BS degree in occupational therapy from Soonchunhyang University, Asan, South Korea. She is a licensed occupational therapist with experience in clinical practice and a master student in Occupational Therapy at Soonchunhyang University. Her current research interests include assisted device, and tele-rehabilitation.

Sang-Heon Lee received Ph.D. degree in occupational therapy from Yonsei University in Wonju, South Korea. He is a professor in the department of Occupational Therapy at Soonchunhyang University. His current research interests include occupational science, occupational therapy evaluation, and motor rehabilitation.

Bong-Keun Jung received doctoral degree in occupational therapy from Washington University in St. Louis, Missouri, the USA. He is a professor in the department of Occupational Therapy and a principal investigator at ICT Convergence Rehabilitation Engineering Research Center at Soonchunhyang University. His current research interests include rehabilitation engineering, driving rehabilitation, and disability policy.