2012 Sixth International Conference on Complex, Intelligent, and Software Intensive Systems

Hand grip strength on a large PDA: holding while reading is different from a functional task

Fateme Rajabiyazdi, Tom Gedeon
Research School of Computer Science, College of Engineering and Computer Science
The Australian National University
Canberra ACT 0200, Australia
fateme.rajabiyazdi@anu.edu.au, tom.gedeon@anu.edu.au

***Abstract*— several studies have been done measuring preferred hand grip strength, but none of them has measured preferred hand strength on a PDA or similar device when it is held and used. We measured dominant hand strength in two conditions similar to real PDA use; resting fore-arms on a table and holding the PDA without table support. We found that adult participants squeeze the device with their preferred hand significantly more than with their nonpreferred hand while holding. In addition, we examined users' hand strength while they were tapping on the back of the device with their right and left index fingers. Our results were different than expected from previous studies, as we found that there was no significant difference in dominant and non dominant hand strength during back tapping. Also participants' non preferred hand strength was not significantly different with their preferred hand when they tap on the back of the device. The results show that in such functional use during tapping, the dominant and non-dominant hands are used similarly which will contribute to future designs for PDAs and their interfaces. Our results may also contribute to design for more comfortable devices for users with hand disabilities.**

Keywords-component; Strengh; prefered hand; non prefered hand; holding; PDA; Back Tapping

I. INTRODUCTION

How users hold devices is a concern in term of PDA design, as the devices get larger. In future PDA designs, trackpad position could be at the front or back of the device. For example a new large screen PDA is introduced with a trackpad at the back [1]. It is known that a PDA has to be designed for the wider population [2] so trackpad position could be on either side of the device; right or left, or both.

If a new large iPad were to be manufactured, it will have a heavier weight than the existing iPad due to the increased size of the device. Therefore, possible issues in holding such a heavier device need to be considered. From previous work on grip strength, it seems plausible to consider an iPad with asymmetric weight as a solution so the weight on a weaker hand is reduced. However, in terms of designing asymmetric PDAs, it is necessary to know which side of the iPad should be heavier. The idea of having asymmetric iPad would be productive if human dominant and nondominant hands have different holding force. If users have similar hand holding force, an iPad with asymmetric weight is not sensible.

The study has two majors intentions: First, measuring maximum and average strength of dominant hand under two conditions; with resting hand on table and without resting hand. Second, finding any relationship between tapping strength with the preferred hand and tapping strength with the nonpreferred hand. The second experiment is to discover if there is a difference between hand strength in a functional setting, that is, while the user is tapping at the back of a PDA.

The participants' hands' grip force is measured by using two force sensors. We report the hand grip force in grams in our experiment, similar to previous work in the literature.

In addition to PDA design, our studies could be useful in designing prosthetic hands [3, 4], designing new mobile phone physical body and implementing ergonomic workplaces [5]. The second study especially can be useful in designing new input systems for tablets or PCs like the RearType prototype [6] or for pressure sensitive keyboards [7].

II. RELATED WORK

Handedness is an important aspect in PDA design. In a hand preference questionnaire by Annet [3], male and female participants did not show any differences in their preferred hand. The questions asked users which hand they prefer to use for completing an action from right, left and either. It was found that handedness could vary from 6 to 17 percent for different actions. Writing had the least percentage of 'either hand' preference and a number of actions were performed with the left hand even less than writing. To match the literature we review, we use 'left' and 'right' as well as 'preferred' and 'nonpreferred' or 'dominant' and 'nondominant'. Similarly, we use 'user', 'subject' and 'participant'.

Usually the preferred hand is considered to be the hand with better performance in common actions like writing. A study on hand preference [4] shows that handedness is not recognizable based on accuracy of a movement control. Moving a single finger or pairs of fingers was more accurate by the left hand than for the right. The left hand of right handed participants was much more consistent than their right hand.

Using the dominant or nondominant hand or using both at the same time usually affects the users' performance. A tabletop device was designed that allows users to manipulate

978-0-7695-4687-2/12 $26.00 © 2012 IEEE
DOI 10.1109/CISIS.2012.110

virtual 3D models to observe humans' work distribution between two hands [5]. Navigation and manipulation tasks can easily be done with training by using two hands.

Using the dominant hand for gripping or pinching is significantly different from using the nondominant hand [6]. They found stronger right hand strength for right handed subjects but not significantly stronger left hands in left handed subjects. This may be due to many activities requiring the use of the right hand in daily life, so left handed people are obliged to use their right hand as well as their left hand.

Age, height and weight have effects on grip strength. A study [7] on 5 to 18 year old school student in Australia shows boys' strength is increasing when they grow up from 5 to 18 years old. However, girls' strength only increases up to the age of 13 and remains constant up to the age of 18 years. Another study [8] on age effects on hand strength shows an increasing curve from childhood to adulthood and then falling from 50 years old.

The core idea of our paper is to examine preferred and nonpreferred hand strength when adult participants hold a device like a PDA. Also the difference between tapping strength in dominant and non dominant hand between right handed and left handed participants is measured. We had an equal number of left and right handed users in our experiments to reduce effects of other factors.

Grip strength and fatigue has been studied in three experiments unrelated to PDAs. The experiments were done with single tap repletion, 10 tap and 30 tap repetitions. In all experiments, the grip strength of the dominant hand was significantly higher than the nondominant hand, but with the passing of time spent gripping, the difference reduced [9].

Fatigue in the dominant hand becomes higher than in the non dominant hand during experiments. Males always have more average grip strength than females, which is expected because of their larger average body size [9]. The authors only had 3 left handed out of 51 participants which could have affected their results. We therefore decided to have the same number of right and left handed in our experiments, rather than matching the population.

In another study, it was found that the tapping performance of dominant hands is higher than with nondominant hands. Single and sequential tapping performance of 60 left and 24 right handed university students were measured in two conditions; dual task and no load. Dominant hand performance was significantly higher than nondominant hand in both single and sequential tapping task under no load condition. In the single tapping experiment, all dual task conditions significantly decrease tapping performance compared to no load condition. However, in the sequential tapping experiment only the reading task reduced performance [10].

Tapping with right or left index fingers has significantly different strength [11]. The authors asked users to tap as fast as possible. Handedness differences in performance were found while participants were tapping. The average tapping rate of the right hand was found to be higher than left hand in both right and left handed groups. Interestingly left handed participants were faster than right handed ones while they were tapping. This shows the weakest hand is belong to left hand of right handed [11]. In the study above a significant gender difference was found in tapping performance. The authors found men's tapping speed was faster than women's speed, which was verified by Schmidt et al.'s [12] results.

Based on the literature, we expect right handed participants to grip more strongly with their right hands, and less strongly with their left. For left handed participants we expect a reduced difference, or possibly no difference. There are no results in the literature for grip strength during tapping, which is significant for a PDA. The lift strength results suggest that we will have similar results for our functional task with a clear difference for right handed participants and a reduced difference for left handed participants.

III. EXPERIMENT DESIGN

A. Experiment One – Design

A 15-inch MacBook screen was separated and the screen aluminum case from its back is used for the experiment to simulate a large PDA device with a well designed aspect ratio. We attached two force sensors at the back of the case with a surface sized so that participants put their fingers on them when they hold the device. The total device weighs approximately 1.1 kg due to the size of the sensor surfaces. This is about double the weight of a current model iPad, which is half the size of our 15-inch simulated device.

We tried to simulate situations that users normally encounter when they hold a device like a PDA to read. Two situations are considered for; sitting at a table, and so having a hand rest for the forearms and without a hand rest. Participants are asked to read a different paragraph for each test. In addition, to reduce fatigue effects on the experiment result, a beep sounds every 25 seconds. We mentioned to users to have 2 seconds break when they heard the beep sound and then continue reading.

Participants' hands strength data were collected every five seconds during each 25 second period. The number of 25 second periods depends on the time participants spent on reading the paragraphs. Then we compared participants' hand strength in both tests to see the difference between hand strength with or without having a table for a hand-rest.

1) On table strength test

In this test, subjects were asked to fit the chair height to feel comfortable. They sit on the chair in front of a table in the experiment room which they are informed is for a hand-rest, for resting their forearms on. A paragraph with roughly 300 words from a children's storybook [13] was given to users to read and we measured their hands strength during their reading time. A children's book was used to ensure the text was non-challenging to all participants to avoid the possible effect of text complexity causing stress and possibly greater grip strength consequently.

2) Off table strength test

Subjects are again asked to seat themselves comfortably on the chair but this time the table is not available for resting

their hands. To avoid learning effects [14] on reading time and skill, a different paragraph from the previous test is chosen. The paragraph was given to users to read has roughly 300 words from the same children's story book [13]. We expect dominant hand strength will be more than the nondominant hand when participants do not use the table as a hand rest.

B. *Experiment Two - Design*

This experiment is to simulate PDA devices with trackpads at the back. We want to examine the difference between positioning a PDA back trackpad at the left or right side of the device. The similar device is used as in the previous experiment.

In this experiment, there are 10 tasks to follow. The first five tasks are with the right index finger and the second five tasks are the same as the first tasks but with the left index finger. Tasks are in order; tap with the index finger, move it upward, move it downward, move it to right and move it to left. Participants are asked to act the tasks at the back of device as if it was a touch device, hence the 'move it upward' includes a degree of pressure required to create a feeling of friction similar to that experienced in using a touch screen device.

Both right and left handed participants did the ten tasks. Once they hold the device with the dominant hand and did the tasks with their nondominant hand and then they hold it with their nondominant hand and did the tasks with other hand. Their hands strength is measured for each task in both situations.

C. *Participants*

Twelve healthy postgraduate students from a local university participated in the user study. The user study is a between group study which included 6 right handed (4 male and 2 female) and 6 left handed (4 male and 2 female) participants.

Using [15] and [16] studies' results we distinguish the participants' handedness based on their writing hand. Participants were Computer Science and IT students ranging from 25 to 37 (Mean = 28, SD = 3) and participated in both experiments.

To avoid participants' expectations effect on the experiment results we did not inform them before the experiment that we are measuring their hand strength; they were advised it is a reading experiment. After the experiments, we explained the main aim of the experiment to them.

IV. Result and Discussion

A. *Experiment One - Results*

1) *On table results*

The Paired T-test (2-tailed) showed a significant difference in strength between dominant and non dominant hand, T(11) = -3.36, P = 0.00636. The maximum hand grip strength was by a dominant hand (1608gr). This pattern also follows on the maximum and minimum of average strength (Min=609.0gr, Max=899.1gr) which shows significantly higher strength by the dominant hand during holding. (**Error! Reference source not found.**)

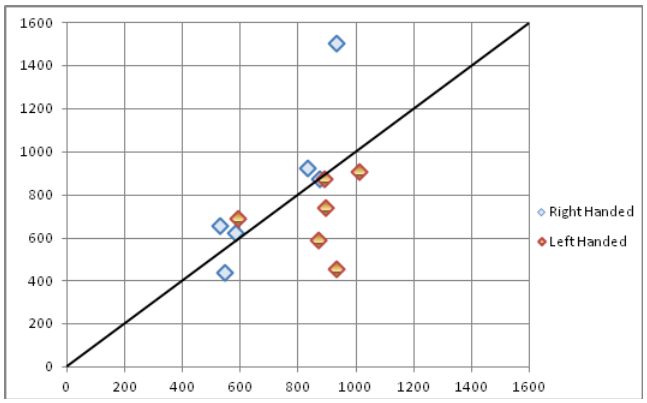

Figure 1. Ratio of the average the right hand strength to the left hand for on table test

Fig.1 shows the ratio of average right handed strength to average left handed strength. It is clear that most of left handed ratio is under the line which means they have stronger left hands. Also most right handed are above the line which means they have stronger right hands.

2) *Off table results*

In the off table test the Paired T-test (2-tailed) showed a significant difference in grip strength between dominant and non dominant hand, T(11) = 2.38, P = 0.0362. In addition to T-test results the maximum of average strength in all 25 second periods among dominant and non dominant hands belonged to a dominant hand (980.4 gr) and the minimum average strength (677 gr) was for a non dominant hand which was as expected. Also the maximum hand strength is in the group of dominant hands and is 1778 gr.

Figure 2 shows the ratio of right hands' average grip strength to left hands' average strength in the off table test. Similarly to the on table test, the results shows most right hand strengths average above the line and left handed strengths under the line.

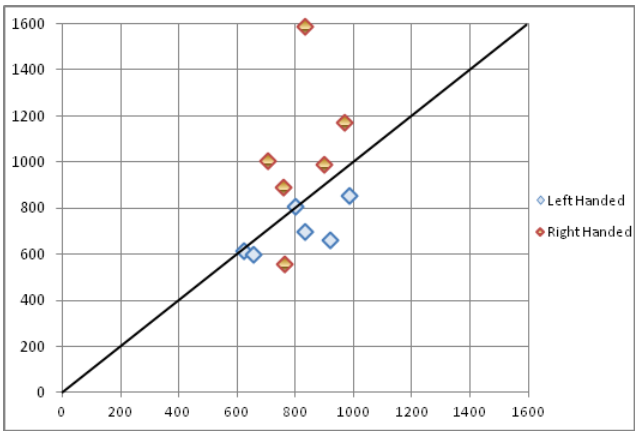

Figure 2. Ratio of the average the right hand strength to the left hand for off table test

3) On/Off table comparison results

We ran the Paired T-test (2-tailed) on the results of hand strength from the first and second tests. There is a significant difference between holding a device with having a hand rest and without a hand rest with the dominant hand, T(5) = -4.8129, P = 0.004828. But there is no difference between non dominant hand strength while holding a device on or off table, T(5) = -1.3217, P = 0.2435.

B. Experiment Two - Results

1) Dominant hand vs. non dominant hand

We compared the tasks done with the dominant hand versus nondominant hand. There was no significant difference between dominant and nondominant hand in these tasks. It is interesting that by placing a (simulated) PDA trackpad at the back, no significant difference was found in users' grip strength between positioning it at the left side or right side for both left and right-handed users. Table 2 shows the results of the Paired T-test (2-tailed).

2) Right tasks vs left tasks

There is no significant difference between right and left tap, move right index finger to up/down and move left index finger to up/down and move right index finger to right/left and move left index finger to right/left. This result came from running the T-test on tasks with right index finger and tasks with left index finger (See Table 3 for the T-test results).

3) Right handed vs left handed

We analyzed the second experiment results to examine the difference between right handed and left handed participants in both tasks type; tasks were done with right index finger and tasks were done with left index finger.

a) Tasks with the right index finger

The Paired T-test (2-paired) results for tapping with right index finger does not show any significant difference between right handed and left handed users, P-value = 0.540. From this result it is clear that position of a back trackpad on a PDA does not change either left or right handed users' grip strength.

Also there is no significant difference between right and left handed participants' grip strength which emphasizes the above result. Fig.3 shows the average summary of tasks with the right index finger.

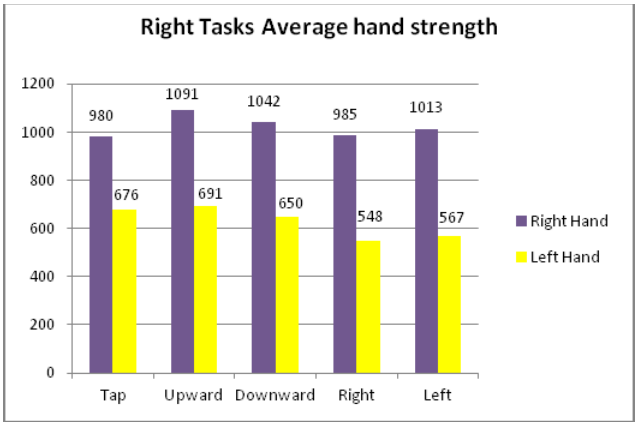

Figure 3. Average summary of tasks with the right index finger

b) Tasks with the left index finger

For the left tasks we found the same results as were achieved for the right side tasks. There is no significant difference between left and right handed grip strength on tasks which used the left index finger. The Paired T-test results for tapping (T(4) = -0.003, P-value = 0.998), moving the index finger up (T(4) = -0.311, P-value = 0.771), moving the index finger down (T(4) = 0.628, P-value = 0.564), moving the index finger to right (T(4) = -0.119, P-value = 0.911) and moving the index finger to left (T(4) = 1.066, P-value = 0.346) verifies the right tasks' results, none are significant, which is an unexpected result. (See Figure 4)

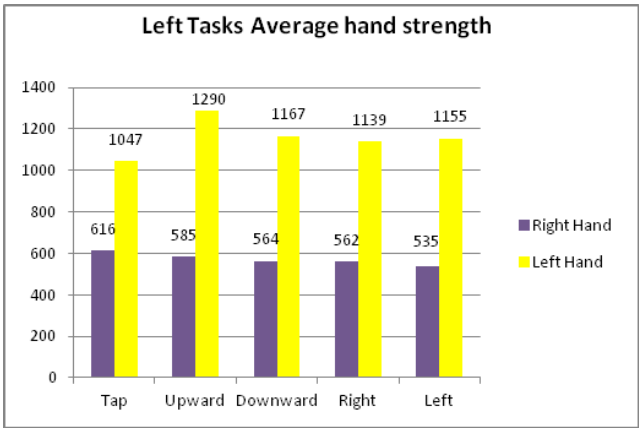

Figure 4. Average summary of tasks with the left index finger

V. DISCCUSION AND CONCLUSION

We presented two user studies that simulated human hand grip behavior while holding a PDA. The first study was done with two different conditions; having a hand rest using a table and without having a rest. These tests compared dominant and nondominant hand grip strength while users hold a 15-inch simulated PDA device. From the objective measures, we demonstrated that dominant hand strength is

significantly higher than nondominant hand while users hold the device in both conditions. This was an expected result and in line with previous related literature.

The difference between hand performances could have physical reasons. Several studies show the dominant and nondominant hand differs in the motor system. A lower threshold for hand muscles activation was found in dominant hands [17]. In addition, a larger area was found in the dominant motor cortex and similarly a larger distal forelimb for the dominant hand than the nondominant hand was found by Nudo et al. [18]. These findings for dominant and nondominant hand confirm that dominant hands are generally stronger, and exert stronger grip during holding.

The second experiment examined the difference between hand grip strength while a user taps or moves the index finger at the back of a PDA. We found no significant difference between the force of dominant and nondominant hands for tapping at the back of the device and moving the index finger up, down, to right and left at the back of the device.

The second experiment measured the difference between right handed and left handed users in the tasks with their right index finger. After analyzing the data, no significant difference was found between the right and the left handed users' right index finger strength in completing the right tasks. The same results also were found for tasks with left index fingers. As mentioned before all tasks were done with index fingers at the back of the device. Using the index finger at the back is not a familiar task for participants. So it is possible no significant difference between the right and the left handed users index finger strength could be due to users' unfamiliarity with tasks at the back, or that the task relates to some finger activities done by both hands.

Our results have indications for the physical design and interface design for large PDAs. Previous work suggests asymmetrical weights would be ok (and may be caused by battery weight for example), and single trackpads under the dominant hand. Meanwhile our result on a simulated PDA in a functional task suggests symmetrical weighting and that dual trackpads used by both hands interchangeably are more suitable.

It is clear that the use of our functional setting simulating the kinds of actions which will be performed on a device provided quite different results from the previous literature and our results for simple holding of the device while reading.

VI. FUTURE WORK

Our experiment shows no significant difference in hand strength between right and left trackpad position while a PDA has a symmetric weight spread in the device. Each trackpad added at the back of device, creates an extra weight to be added to the PDA weight.

With a single added trackpad, a PDA could have an asymmetric weight with a heavier side. A further study should examine the difference between right and left hand strength using a PDA with asymmetrical weight. That study has to be able to show if it is possible to have an extra weight on one PDA side without adverse effects on the tasks performance.

We only measured the hands' grip strength for using a back trackpad. We found that in the functional task setting there was no difference related to hand dominance. An experiment to track accuracy at the back should be done next to determine which of our possible explanations is correct. We note that since large PDA devices of the size we envision and with a weight we consider sensible are not yet actually available (unlike much heavier tablet devices), so we are limited to simulating single properties at a time.

ACKNOWLEDGMENT

The authors would like to express their appreciations to all participants of the experiments, and thank Dr. Duncan Stevenson for his helpful comments and suggestions.

REFERENCES

[1] F. Rajabiyazdi, and T. Gedeon, "Comparing User Performance on an iPad to a 17" BackPad," *Tech Report TR-CS-11-03, Research School of Computer Science, Australian National University*.

[2] M. Dunlop, and S. Brewster, "The challenge of mobile devices for human computer interaction," *Personal and Ubiquitous Computing,* vol. 6, no. 4, pp. 235-236, 2002.

[3] M. Annet, "A classification of hand preference by association analysis," *British journal of psychology,* vol. 61, no. 3, pp. 303-321, 1970.

[4] D. Kimura, and CH. Vanderwolf, "The relation between hand preference and the performance of individual finger movements by left and right hands," *Brain,* vol. 93, no. 4, pp. 769-774, 1970.

[5] L.D. Cutler, B. Frohlich, P. Hanrahan, "Two-handed direct manipulation on the responsive workbench," in *ACM*, 1997.

[6] N. A. Incel, E. Ceceli, P. B. Durukan, H. R. Erdem, Z. R. Yorgancioglu, "Grip strength: effect of hand dominance," *Singapore medical journal,* vol. 43, no. 5, pp. 234-237, 2002.

[7] DG. Newman, and J. Pearn, and A. Barnes, and CM. Young, and M. Kehoe, and J. Newman , "Norms for hand grip strength," *Archives of disease in childhood,* vol. 59, no. 5, pp. 453-459, 1984.

[8] L. Peebles, and B.Norris, "Filling 'gaps' in strength data for design," *Applied Ergonomics,* vol. 34, pp. 73-88, 2003.

[9] M. Ameli, M. Dafotaski, G.R. Fink,D.A. Nowak, "Predictive force programming in the grip-lift task: The role of memory links between arbitrary cues and object weight," *Neuropsychologia,* vol. 46, no. 9, pp. 2383-2388, 2008.

[10] C.W. Nicolay, and A.L. Walker, "Grip strength and endurance: Influences of anthropometric variation, hand dominance, and gender," *International Journal of Industrial Ergonomics,* vol. 35, no. 7, pp. 605-618, 2005.

[11] M. Peters, and B. M. Durding, "Handedness measured by finger tapping: A continuous variable.," *Psychology/Revue canadienne de psychologie,* vol. 32, no. 4, pp. 257-261, 1978.

[12] S.L. Schmidt, R.M. Oliveira ,T.E. Krahe, and C.C. Filgueiras, "The efects of hand preference and gender on finger tapping performance asymmetry by the use of an infra-red light measurement device," *Neuropsychologia,* vol. 38, no. 5, pp. 529-534, 2000.

[13] R. Goscinny, and J.J. Sempé, Nicholas on Vacation, Phaidon Press, 2006.

[14] J. Lazar, J. H. Feng , and H. Hochheiser , Research Methods in Human-Computer Interaction, Wiley, 2010.

[15] I. C. McManus, "Genetics of handedness in relation to language disorder," *Advances in neurology,* vol. 42, pp. 125-138, 1984.

[16] T. Rasmussen, and B. Milner, "The role of early left-brain injury in determining lateralization of cerebral speech functions," *Annals of the New York Academy of Sciences,* vol. 299, no. 1, pp. 355-369, 1977.

[17] W.J. Triggs, R. Calvanio, R.A.L. Macdonell, D. Cros, K.H. Chiappa, "Physiological motor asymmetry in human handedness: evidence from transcranial magnetic stimulation," *Brain Research,* vol. 636, no. 2, pp. 270-276, 1994.

[18] R.J. Nudo, R.WM. Jenkins, M.M Merzenich, T. Prejean, and R. Grenda, "Neurophysiological correlates of hand preference in primary motor cortex of adult squirrel monkeys," *The Journal of neuroscience,* vol. 12, no. 8, 1992.

		First 25 seconds Mean(gr)±SD (Min-Max)	Second 25 seconds Mean(gr)±SD (Min-Max)	Third 25 seconds Mean(gr)±SD (Min-Max)	Forth 25 seconds Mean(gr)±SD (Min-Max)	Fifth 25 seconds Mean(gr)±SD (Min-Max)	Sixth 25 seconds Mean(gr)±SD (Min-Max)
On table test	**Dominant hand**	753.2±372.5 (1-1608)	740.9±216.7 (166-1065)	899.1±204.7 (417-1224)	851.3±147.3 (551-1130)	892.6±91.9 (551-1002)	805.1±174.8 (660-986)
	Nondominant hand	609.0±226.4 (3-960)	688.1±189.0 (284-1071)	728.0±191.6 (391-1030)	772.4±211.3 (396-1189)	692.8±159.0 (462-885)	804.5±302.6 (436-1070)
Off table test	**Dominant hand**	880.7±271.2 (551-1666)	888.9±278.3 (546-1734)	980.5±301.8 (452-1778)	928.1±191.0 (491-1285)	934.6±202.3 (651-1188)	846.3±0 (786-918)
	Nondominant hand	705.5±104.1 (537-1150)	677±117.7 (480-1057)	721.9±108.2 (567-1052)	825.4±110.9 (514-1122)	761.8±51.6 (690-1002)	766.5±0 (665-897)

Table 1 . Summary of measures of strength for on/off table tests

	P-Value	T	Right Mean (gr)±SD	Left Mean (gr)±SD
Tap	0.681 >0.05	0.4247	675.8±407.2	616.2±350.3
Move Up	0.677 >0.05	0.4312	690.6±344.3	585.1±309.7
Move Down	0.739 >0.05	0.3431	649.5±348.9	563.7±242.1
Move to Right	0.823 >0.05	-0.231	547.8±266.2	562.2±275.3
Move to Left	0.999 >0.05	0.0015	566.7±311.8	535.1±307.4

Table 2. T-test, mean, SD, Min and Max summary second experiment results between tasks with right hand and tasks with left hand

	P-Value	T	Mean (gr)±SD dominant hand	Min-Max(gr) dominant hand
			Mean (gr)±SD nondominant hand	**Min-Max(gr) nondominant hand**
Tap	0.276 >0.05	1.160	682.6±372.6	17-810
			602.7±230.0	294-959
Move Up	0.886 >0.05	-0.148	643.3±289.6	49-827
			626.6±274.1	283-1134
Move Down	0.837 >0.05	-0.212	594.8±337.0	57-1007
			615.3±232.4	275-953
Move to Right	0.423 >0.05	0.840	551.0±283.0	19-589
			560.2±129.8	345-732
Move to Left	0.581 >0.05	0.573	584.6±302.3	72-659
			512.3±161.1	201-639

Table 3.Summary of T-test results on second experiment tasks