Chapter 1

The Effects of Hand Strength on Pointing Performance

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1.1 Introduction

Pointing tasks form a significant part of human-computer interaction in graphical user interfaces. Fitts' law (Fitts, 1954) and its variations (Mackenzie, 2003) are widely used to model pointing as a sequence of rapid aiming movements, especially for able-bodied users. Fitts' Law predicts the movement time as a function of the width and distance to the target. This law is found to be very robust and works in many different situations (even in space and under water). However the application of Fitts' Law for people with motor impairment is less clear. We have investigated also how the pointing performance of people with motor impairment varies from their able-bodied counterparts. In particular, we have studied how physical strength affects the pointing performance of people with and without motor impairment for different input devices. We have used this study to develop a simulator to help with the design and evaluation of assistive interfaces (Biswas and Robinson, 2008b). The simulator embodies both the internal state of a computer application and also the perceptual, cognitive and motor processes of its user. It takes a task definition and locations of different objects in an interface as input. It then predicts possible eye movements and cursor paths on the screen and uses these to predict task completion times. We hope this study will be helpful to understand and analyse the interaction patterns of people with motor impairment and design better assistive interfaces for them. It will also help in explaining motor action and developing better motor-behaviour models for motor impaired users.

In this study, we have measured the physical strength of users by evaluating their hand strength in terms of flexibility and maximum exerted force. It has already been found that the active range of motion (ROM) of the wrist is significantly correlated with movement time in a Fitts' Law task for children with spasticity (Smits-Engelsman *et al.*, 2007). Hand evaluation devices are cheap, easy to operate and have good test-retest reliability (Mathiowetz *et al.*, 1984). So these are reliable and useful tools for measuring physical strength making these results useful in practice. Our study consisted of the following three experiments:

1. the first experiment involved pointing tasks using a mouse and was undertaken by both motor impaired and able-bodied participants;
2. the second experiment involved pointing tasks using single switch scanning techniques and was undertaken by both motor impaired and able-bodied participants;
3. the third experiment involved two dimensional Fitts' Law pointing tasks using a mouse, and was undertaken only by able-bodied participants.

The remainder of this paper presents the experiments in more detail.

1.2 Experiment One: Pointing Tasks

1.2.1 Procedure, Material and Participants

Our study consisted of pointing tasks. A sample screenshot of the task is shown in Figure 1.1. We followed the description of the multiple tapping tasks in ISO 9241 part 9 (ISO, 2000). In this task the pointer initially located at the middle of the screen. The participants had to move it towards a target (one of the red dots, appearing a light grey in monochrome), and click on it. This process was repeated for all the targets. There were eight targets on the screen and each participant performed the test twice (except participant P2, who retired after completing the first test). The distances to the targets ranged from 200 to 600 pixels while target widths were randomly selected as an integer between 16 and 48 pixels.

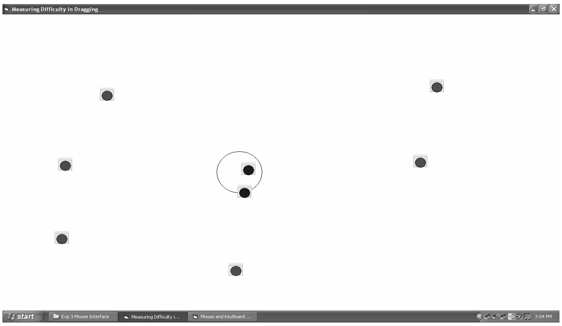

Figure 1.1. Screenshot of the experiment for mouse interface

We used a standard optical Mouse and an Acer Aspire 1640 Laptop with a 15.5” monitor having 1280×800 pixel resolution. We also used the same seating arrangement (same table height and distance from table) for all participants.

We measured the following six variables for hand strength evaluation. Each was measured three times and we took the average. We evaluated only the dominant hand (the hand participants used to operate the mouse). Photographs of the measurement technique can be found at reference (Kaplan, 2006). Grip strength measures how much force a person can generate by gripping by hand. We measured it using a mechanical dynamometer. Tip pinch strength measures the maximum force generated by a person squeezing something between the tips of his thumb and index finger. We measured it using a mechanical dynamometer. The following ranges of motion are defined with respect to the standard anatomical position (Kaplan, 2006).

Radial deviation is the motion that rotates the wrist away from the midline of the body when the person is standing in the standard anatomical position (Kaplan, 2006). When the hand is placed over a table with palm facing down, this motion rotates the hand about the wrist towards the thumb. We measured the maximum radial deviation using a goniometer. Ulnar deviation is the motion that rotates the wrist towards the midline of the body when the person is standing in the standard anatomical position. When the hand is placed over a table with palm facing down, this motion rotates the hand about the wrist towards the little finger. We measured it with the goniometer. Pronation is the rotation of the forearm so that the palm moves from a facing up position to a facing down position. We measured it using a wrist-inclinometer. Supination is the opposite of pronation, the rotation of the forearm so that the palm moves from a facing down position to a facing up position. We measured it with the wrist-inclinometer.

We collected data from 10 motor impaired and six able-bodied participants (Table 1.1, next page). The motor impaired participants were recruited from a local centre, which works on treatment and rehabilitation of disabled people and they volunteered for the study. To generalise the study, we selected participants with both hypokinetic (*e.g.* restricted movement, participants P1, P3, P4 *etc.*) and hyperkinetic (*e.g.* uncontrolled movement/tremor, participants P5, P6 *etc.*) movement disorders (Flowers, 1976). All motor impaired participants used a computer at least once each week. Able-bodied participants were students of our university and expert computer users.

1.2.2 Results

We found that the movement time significantly correlates (ρ = 0.57, $p < 0.001$) with the number of pauses. We defined a pause as an instance while the pointer does not move for more than 100 msec. We correlated the average number of pauses per pointing task with the hand strength metrics. Figure 1.2 shows the graphs of average number of pauses per pointing task with respect to the Grip Strength. We found that some users did not have any range of motion in their wrist, though they managed to move the mouse to perform the pointing tasks correctly. We also found that the natural logarithm of grip strength significantly correlates with the mean (ρ = -0.72, $p < 0.001$) and standard deviation (ρ = -0.53, $p < 0.05$) of the number of pauses per pointing task. We did not find any correlation between that movement time and the distance, width or Fitts' Law index of difficulty (ID) (Fitts, 1954) of the targets for motor impaired users. This may be due to the presence of physical impairment and the number of pointing tasks (only 16) performed by the participants. We also did not find any significant correlations involving ranges of motion. More details about these results can be found in a separate paper (Biswas and Robinson, 2009).

Table 1.1. List of participants

	Age	Gender	Impairment
C1	30	M	Able-bodied
C2	29	M	
C3	28	M	
C4	25	M	
C5	29	M	
C6	27	F	
P1	30	M	Cerebral Palsy reduced manual dexterity wheel chair user
P2	43	M	Cerebral Palsy reduced manual dexterity also some tremor in hand wheel chair user
P3	25-45	F	One handed (dominant hand) the other hand is paralysed
P4	30	M	Dystonia cannot speak cannot move fingers wheelchair user
P5	62	M	Left side (non-dominant) paralysed after a stroke in 1973 also has tremor
P6	44	M	Cerebral attack significant tremor in whole upper body part fingers always remain folded
P7	46	F	Did not mention disease difficulty in gripping things no tremor
P8	>45	F	Spina Bifida/ Hydrocephalus wheelchair user
P9	43	F	Did not mention disease restricted hand movement no tremor
P10	>45	M	Cerebral Palsy from birth restricted hand movement no tremor.

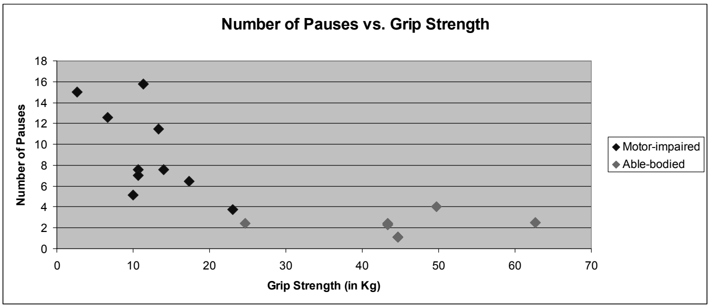

Figure 1.2. Average number of pauses per pointing task vs. grip strength

We divided the whole movement path into three phases (Biswas and Robinson, 2008b, 2009) and observed how the hand strength affects in the initial, main movement and homing phases. We found that grip strength significantly correlates with the average number of pauses near the source (ρ = -0.61, $p < 0.01$) and near the target (ρ = -0.78, p < 0.001). We also found that the mean and standard deviation of the velocity of movement were significantly correlated with grip strength (Figure 1.3, ρ = 0.82, p < 0.001 for mean and ρ = 0.81, p < 0.001 for standard deviation).

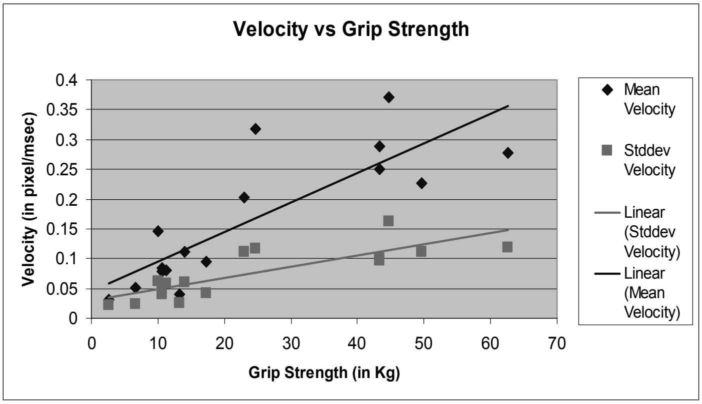

Figure 1.3. Velocity of movement vs. grip strength

1.3 Experiment Two: Scanning Study

Many physically challenged users interact with a computer through one or two switches with the help of a scanning mechanism. Scanning is the technique of successively highlighting items on a computer screen and pressing a switch when the desired item is highlighted. In this study we used two scanning systems. A block scanning system iteratively segments the screen into equally sized sub-areas. The user has to select a sub-area that contains the intended target. The segmentation process iterates until the sub-area contains a single target. A cluster scanning system iteratively divides the screen into several clusters of targets based on their locations. The user has to select the appropriate cluster that contains the intended target. The clustering process iterates until the cluster only contains a single target. Details of these scanning systems can be found in our previous paper (Biswas and Robinson, 2008a).

1.3.1 Procedure, Material and Participants

In this experiment, the participants were instructed to press a set of buttons arranged on a screen (Figure 1.4) in a particular sequence. All of the buttons were coloured grey except the next target, which was red. After selecting the target its colour changed to grey and another target became red. The same task was repeated for both the scanning systems. We recorded the cursor trajectories, target height, width, and task completion time. For internal validity of the experiment, the scan delay was kept constant at two seconds for all motor impaired participants and at one second for the control group since the reaction times of motor impaired users were longer. These values were selected to exceed their maximum measured reaction time. All participants were trained adequately with the scanning systems before undertaking the experiment.

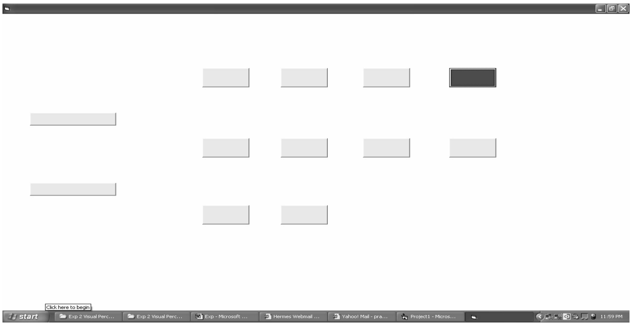

Figure 1.4. Screenshot of the experiment

We used a push button switch (The Super-Switch, 2007) and an Acer Aspire 1640 Laptop with a 15.5" monitor having 1280×800 pixel resolution. We used the same seating arrangement for all participants. We measured the same six variables for hand strength evaluation as in Experiment One.

We collected data from eight motor impaired (all participants except P3 and P9 in Table 1.1) and eight able-bodied participants (five female, three male, average age 28.75). The motor impaired participants were recruited from a local centre and they volunteered for the study. All motor impaired participants used a computer at least once each week. Able-bodied participants were students of our university and expert computer users. None of the participants had used the scanning systems before.

1.3.2 Results

We measured the following three variables to investigate the scanning systems:

- Number of missed clicks: We counted the number of times the participants wrongly pressed the switch.
- Idle count: The scanning systems periodically highlight the buttons. This variable measures the number of cycles when the participants did not provide any input, though they were expected to do so.
- Efficiency: The scanning systems require a minimum time to complete any task which depends on the particular scanning system and not on the performance of the user. We calculated the efficiency as the ratio $\frac{OptimalTime}{ActualTime}$. An efficiency of 100% indicates optimal performance, 50% indicates taking twice the minimal time and 0% indicates failure to complete the task.

Table 1.2 shows the correlation coefficients of these variables with the hand evaluation metrics. The only significant effect is a correlation between the number of missed clicks in the cluster scanning system and grip strength; there was a similar, but weaker, effect in the block scanning system. It seems that hand strength does not affect performance of users with the scanning systems. An equal variance *t*-test did not find any significant difference between the performance of motor impaired and able-bodied users at the $p < 0.05$ level. We also failed to find any effect of target size (height and width) on the task completion time, which is not surprising as the scanning systems did not depend on target size.

Table 1.2. Correlation coefficients for the scanning systems (* significant at p < 0.05)

		Cluster Scanning System			Block Scanning System		
		Missed Click	Idle Count	Efficiency	Missed Click	Idle Count	Efficiency
Correlations	GS	-0.580*	-0.191	0.168	-0.429	-0.331	0.283
	TPS	-0.374	-0.105	0.110	-0.271	-0.153	0.093
	ROM Wrist	-0.414	-0.154	0.189	-0.127	-0.120	0.068
	ROM Forearm	0.000	0.106	-0.079	-0.268	-0.225	0.076
Significance	GS	0.018	0.478	0.534	0.097	0.210	0.289
	TPS	0.153	0.699	0.686	0.310	0.572	0.731
	ROM Wrist	0.111	0.569	0.484	0.639	0.659	0.803
	ROM Forearm	1.000	0.695	0.770	0.315	0.401	0.778

1.4 Experiment Three: Fitts' Law Study

After analysing the effect of hand strength of motor impaired users, we also investigated how hand strength affects performance of able-bodied users. It would help to compare and contrast the pointing patterns of motor impaired users from their able bodied counterpart.

1.4.1 Procedure, Material and Participants

Fitts' Law provides a robust and accurate model for rapid aiming movements of able-bodied users. So we conducted a 2-dimensional Fitts' Law task. We used 26 different combinations of target amplitude (A, ranged from 30 to 700 pixels) and target width (W, ranged from 16 to 48 pixels). The resulting index of difficulty (ID) ranged from 2 to 5. Each participant performed 450 pointing tasks.

We used a standard optical Mouse and an Acer Aspire 1640 Laptop with 15.5” monitor having 1280×800 pixel resolution. We also used the same seating arrangement for all participants. We measured the same six variables for hand strength evaluation as in Experiment One.

We collected data from 14 able-bodied users (nine male, five female, and age range 22 to 50 with average age of 29.3). All participants were expert computer users.

1.4.2 Results

The correlation coefficients between index of difficulty (ID) and movement time ranges from 0.73 to 0.95 with an average value of 0.85, which conforms to Fitts’ Law. We compared the hand evaluation metrics with the Fitts’ Law coefficients (a and b where, $MT = a + b\log_2\left(\frac{A}{W}+1\right)$ and Index of Performance $\left(IP = \frac{ID_{Average}}{MT_{Average}}\right)$. We found that IP is significantly correlated with the grip strength and tip pinch strength ($\rho = 0.57$, $p < 0.05$ for grip strength, $\rho = 0.72$, $p < 0.005$ for tip pinch strength, Figures 1.5 and 6 respectively). The parameter b significantly correlates with tip pinch strength ($\rho = 0.65$, $p < 0.01$, Figure 1.7). We did not find any other significant correlation between IP, a, b and any other hand evaluation metrics.

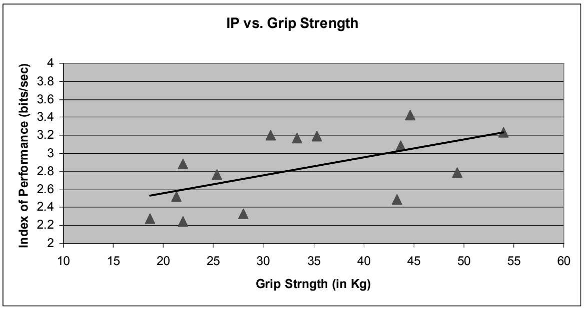

Figure 1.5. Index of performance vs. grip strength

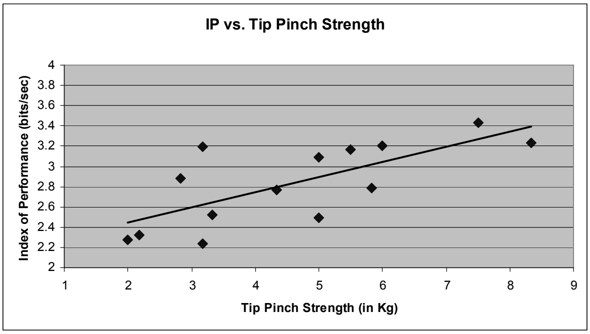

Figure 1.6. Index of performance vs. tip pinch strength

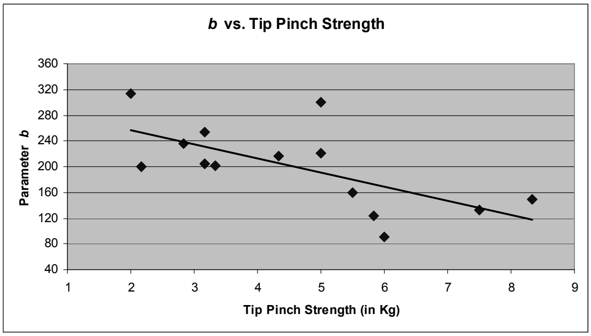

Figure 1.7. Parameter *b* vs. tip pinch strength

1.5 Discussion

For able-bodied users, pointing performance is generally analysed in terms of Fitts' Law. Fitts' Law can be applied to rapid aiming movements in many different contexts, but a proper explanation of this law is still unclear. Crossman and Goodeve pioneered an early by limited mathematical explanation (Rosenbaum, 1991). Meyer and colleagues gave a generalised model of rapid aiming movements in which Fitts' Law comes as a special case; however, alternative explanations are also available (*e.g.* the Mass Spring model) (Rosenbaum, 1991). However, Fitts' Law does not account for the users' physical abilities in predicting movement time. This seems reasonable for able-bodied users. Our analysis indicates that people having higher hand strength also have greater control in hand movement and can perform pointing faster. The positive correlation between the velocity of movement and grip strength also supports this claim. As motor impairment reduces the strength of a hand, motor impaired people lose control of hand movement. So the number of pauses near the source and target are significantly affected by grip strength. The logarithmic relation between grip strength and number of pauses indicates that there is a minimum amount of grip strength (about 20 kg) required to move the mouse without pausing more than twice. This threshold of 20 kg can be used to determine the type of input device suitable for a user, along with other factors like preference, expertise etc. Our analysis also showed that flexibility of motion (as measured by ROM of wrist or forearm) is not as important as strength of hand (as measured by grip strength). We found that hand strength affects pointing performance of able-bodied users, too. The positive correlation between index of performance and hand strength shows people with greater hand strength perform pointing faster. The correlation between the constant term *b* and tip pinch strength indicates a difference in movement patterns among people with different hand strengths. As the constant *b* indicates the effect of index of difficulty (*ID*) on the movement time, perhaps the movement pattern of people with higher hand strength mainly consists of an initial ballistic phase and does not have a long homing phase since time to complete the homing phase should depend more on the target characteristics. The opposite holds true for people with less hand strength.

As the homing phase requires more control in hand-movement, the negative correlation between *b* and hand strength also indicates people having higher hand strength also have greater control in hand movement. We also failed to find any effect of hand strength on pointing performance while participants used the scanning systems. There are two possible explanations:

- the switch used in scanning only requires a gentle push to operate and the hand strength of motor impaired users is sufficient to operate the switch;
- the scanning software does the navigation itself and the users need not move their hand to move the pointer.

This result with the scanning system also shows that an appropriate choice of assistive technology can make interaction independent of the physical strength of users.

1.6 References

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