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I, Aswin Sairam,

hereby submit this work as part of the requirements for the degree of:

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Developing and Verifying MTM modifiers for tasks performed by individuals with permanent partial disability of the fingers

This work and its defense approved by:

Chair: Dr. Anil Mital

Dr. Ronald Huston

Dr. Sam Anand

Developing and Verifying MTM modifiers for tasks performed by individuals with permanent partial disability of the fingers

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Aswin Sairam

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Crescent College of Engineering, Anna University, India, 2006

Committee Chair: Dr. Anil Mital

ABSTRACT

Time Standards for various elemental tasks have been in existence for a long time. These standards are important to maintain productivity and to design wage schemes. Also the standards that exist today have been created for individuals without any disability. But with over 10 percent of American population being affected by some form of disability there is a growing need to accommodate them into the workforce. Hence it is important to create modifiers that can be applied to existing standards so that new standards that are applicable to the disabled population can be created. Research has already been carried out in the area of developing these modifiers for certain types of disabilities. This thesis work mainly focuses on three types of disability: Loss of four fingers in preferred hand, loss of thumb in non-preferred hand and a combination of both. The objective of this work is to verify some of the modifiers for elemental tasks or therbligs that are already in existence and to use the same technique to develop modifiers for computer related tasks such as typing and mouse control.

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1. Introduction

Disabled people have suffered social and economic discrimination for centuries. Discrimination has existed at workplaces, public services and even at educational institutions. Statistics have shown that they suffer from lower levels of income, lesser opportunities to graduate college and depend more on supplemental income. So it is paramount that society does its best to alleviate the sufferings of the disabled by providing them better opportunities. But in the past few years research in to disability and rehabilitation has attracted more attention.

Rehabilitation of the disabled person (post accident or medical illness) is one of the key aspects in bringing back normalcy to his/her life. This is achieved by studying the impact of the particular disability on the quality or speed of work done as compared to normal person. This could vary from very high impact to minimal impact. Once this is established, the organization can try to do its best to accommodate the employee.

1.1 Disability

The Americans with Disability Act (ADA) defines disability as a "physical or mental impairment that substantially limits one or more of the major life activities of such individual" [17].

Before drafting the ADA legislation, the following findings were noted.

- More than 43 million Americans are suffering from one form of disability or the order. This represents a huge percentage of the society that is vulnerable to discrimination[17].
- Historically society has tended to isolate, segregate and discriminate against individuals with disabilities. Though the awareness has been created, this remains a problem[17].
- Discrimination against individuals with disabilities persists in such critical areas as employment, housing, public accommodations, education, transportation[17]. For example,

students with learning disabilities have traditionally been denied accommodations at learning institutions that has resulted in severe economic and social hardships.

- It is also the society's responsibility to provide individuals with disabilities with equal opportunities, full participation, independent living and economic self-sufficiency[17].

One of the most important issues is to identify the boundary between ability and disability. It can be very difficult at times to distinguish between lack of ability to perform a particular task and a disability that would make inhibit a person from person from completing the task. International Classification of Functioning, Disability and health (ICF) is a framework or a unified system developed by World Health Organization that describes health and disability related states [19].

	Part 1: Functioning and Disability		Part 2: Contextual Factors	
Components	Body Functions and Structures	Activities and Participation	Environmental Factors	Personal Factors
Domains	Body functions Body structures	Life areas (tasks, actions)	External influences on functioning and disability	Internal influences on functioning and disability
Constructs	Change in body functions (physiological Change in body structures (anatomical)	Capacity Executing tasks in a standard environment Performance Executing tasks in the current environment	Facilitating or hindering impact of features of the physical, social, and attitudinal world	Impact of attributes of the person
Positive aspect	Functional and structural integrity	Activities Participation	Facilitators	not applicable
	Functioning			
Negative aspect	Impairment	Activity limitation Participation restriction	Barriers / hindrances	not applicable
	Disability			

Figure 1: Concept of ICF (WHO ICF's Introduction to Classification, www.who.int/en)[19]

1.1.1 ICF Classification

ICF information is organized into 2 parts –

Part 1 Functioning and Disability

(a) Body Functions and Structures

(b) Activities and Participation

Part 2 Contextual Factors

(c) Environmental Factors

(d) Personal Factors

Table 1: Concepts involved in ICF (WHO ICF, www.who.int/en) [19]

Concept	Definition
Body functions	physiological functions of body systems
Body structures	anatomical parts of the body such as organs, limbs and their components
Impairments	anomaly, defect, loss or other significant deviation in body structures
Activity	execution of a task or action by an individual
Participation	involvement in a life situation
Activity limitations	difficulties an individual may have in executing activities
Participation restrictions	problems an individual may experience in involvement in life situations
Environmental factors	factors that make up the physical, social and attitudinal environment in which people live and conduct their lives

1.1.2 Medical and Social Models

There are primarily two models to look at disability and to understand it. They are the medical model and the social model. The medical model looks at disability as a problem with an individual caused by illness or disease or a trauma which requires medical treatment. It looks at providing healthcare and curing or rehabilitating the person.

The social model looks at disability as a socially created problem as a matter that requires the full integration of the person into the society. The issue is seen not as an individual's trait but as the collection of factors created by the society. So it looks to solve the problem by changing the attitude of the public.

1.1.3 Americans with Disability Act of 1990

Americans with Disabilities Act of 1990 prohibits private employers, state and local governments, employment agencies and labor unions from discriminating against qualified individuals with disabilities in job application procedures, hiring, firing, advancement, compensation, job training, and other terms, conditions, and privileges of employment [17].

The following are the titles covered by it [17].

1. Employment
2. Public Transportation
3. Public Accommodations
4. Telecommunications Relay Services

A qualified employee or applicant with a disability is an individual who, with or without reasonable accommodation, can perform the essential functions of the job in question. Reasonable accommodation may include, but is not limited to:

- Making existing facilities used by employees readily accessible to and usable by persons with disabilities.
- Job restructuring, modifying work schedules, reassignment to a vacant position;

- Acquiring or modifying equipment or devices, adjusting or modifying examinations, training materials, or policies, and providing qualified readers or interpreters.

1.2 Disability Statistics

The statistics compiled by United Nations organization shows the enormity of the problems associated with disability. It indicates that 650 million people or close to 10% of the world population suffers from some form of disability or the other. The problem is compounded by the fact that many of these disabled people live in the developing world where they have very little access to employment, education or health care.

The study mentions that global literacy rate among the disabled is as low as 3% and 1% for women with disability. International Labor Organization believes that unemployment among the disabled is as high as 80%.

Over 30 million Americans have one form of disability or the other or a combination of disabilities. The table summarizes the disability figures as given in the Census report of 2000.

Table 2: Disability figures as given in US census 2000 report [14, 15]

	Total		Male		Female	
	Number	Percentage	Number	Percentage	Number	Percentage
Population 16 to 64 years	178,687,234	100	87,570,583	100	91,116,651	100
With any disability	33,153,211	18.6	17,139,019	19.6	16,014,192	17.6
Sensory	4,123,902	2.3	2,388,121	2.7	1,735,781	1.9
Physical	11,150,365	6.2	5,279,731	6	5,870,634	6.4
Mental	6,764,439	3.8	3,434,631	3.9	3,329,808	3.7
Self-care	3,149,875	1.8	1,463,184	1.7	1,686,691	1.9
Going outside the home	11,414,508	6.4	5,569,362	6.4	5,845,146	6.4
Employment disability	21,287,570	11.9	11,373,786	13	9,913,784	10.9

The following graph shows the percentage of various forms of disability in USA according to 2000 Census [14, 15]. The disabilities have been classified as sensory, physical, mental, self-care and employment disability.

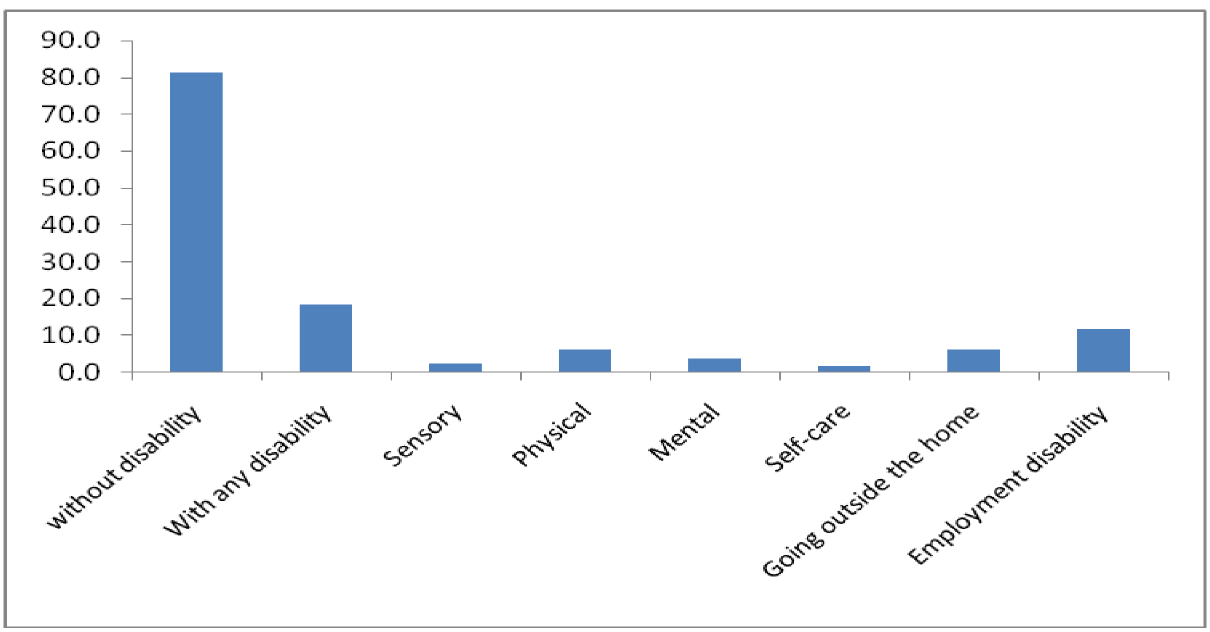


Figure 2: Percentage of people in USA with various forms of disability.

One important issue is the lack of employment and poverty among the disabled people. Figure 3 gives the mean income of people with various disabilities. It clearly shows that people with disability earn much less than the people without disability. Another observation is that people with mental disability earn much less than the people with other disabilities such as sensory and physical disability. One reason for this can be found in figure 6. It shows that people with mental disability have the lowest percentage of college education. Thus lack of university / college degree can be considered as a major reason for lesser mean income and higher poverty rate.

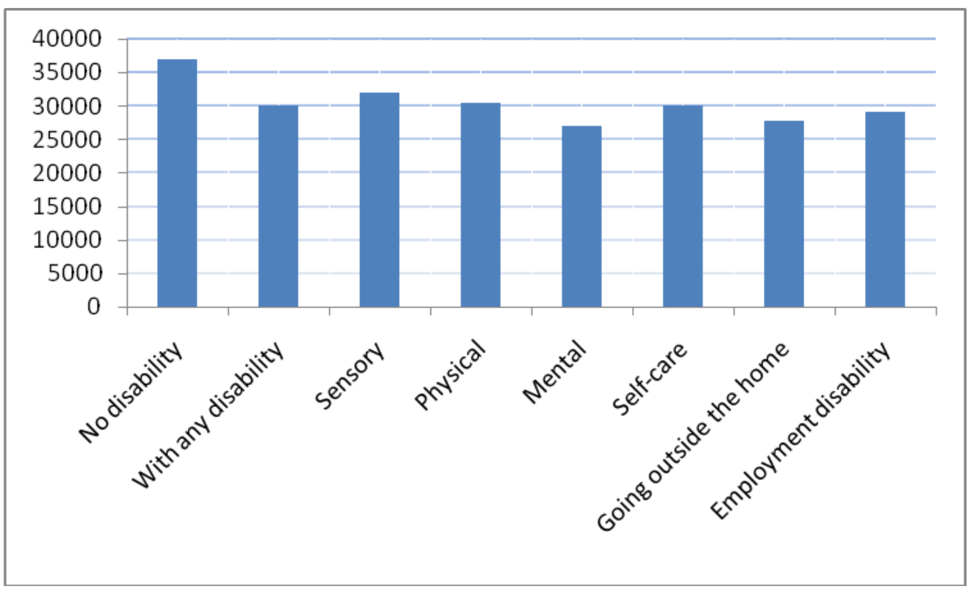


Figure 3: Mean income for people without and with different forms of disability [14,15]

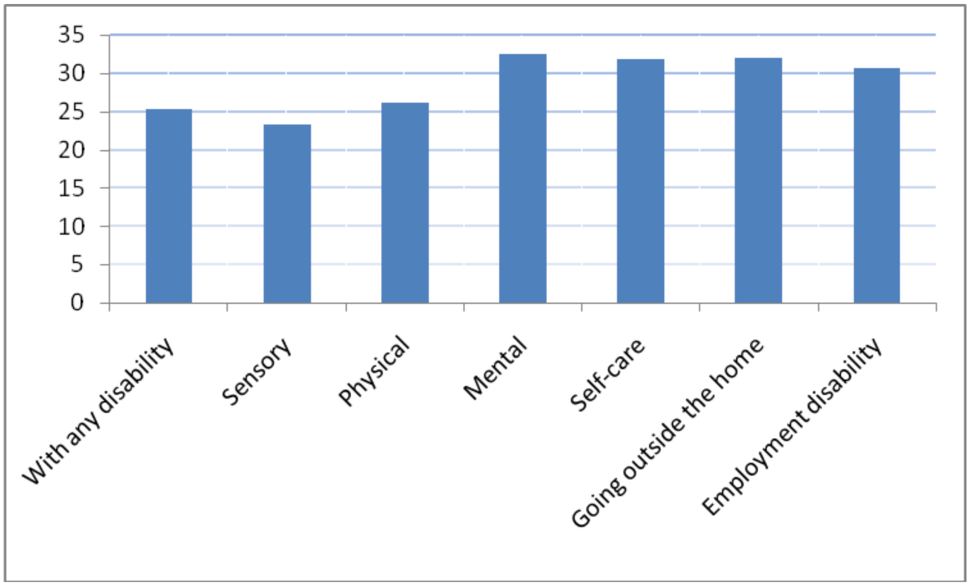


Figure 4: Percentage of people with disability living in poverty [14, 15]

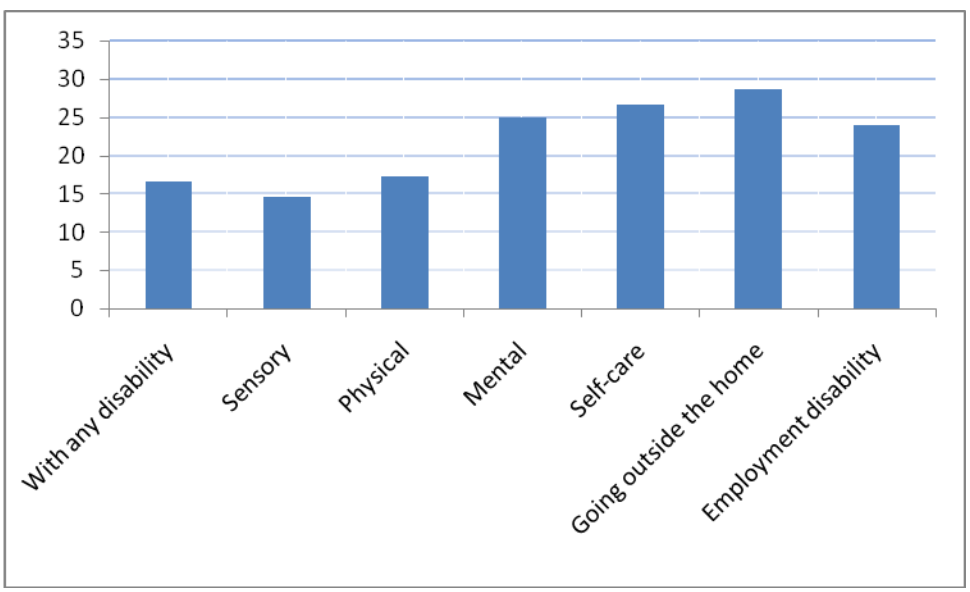


Figure 5: Percentage of people with disability receiving Supplemental Security Income (SSI is a monthly stipend paid to aged and disabled people by the US government) [14, 15]

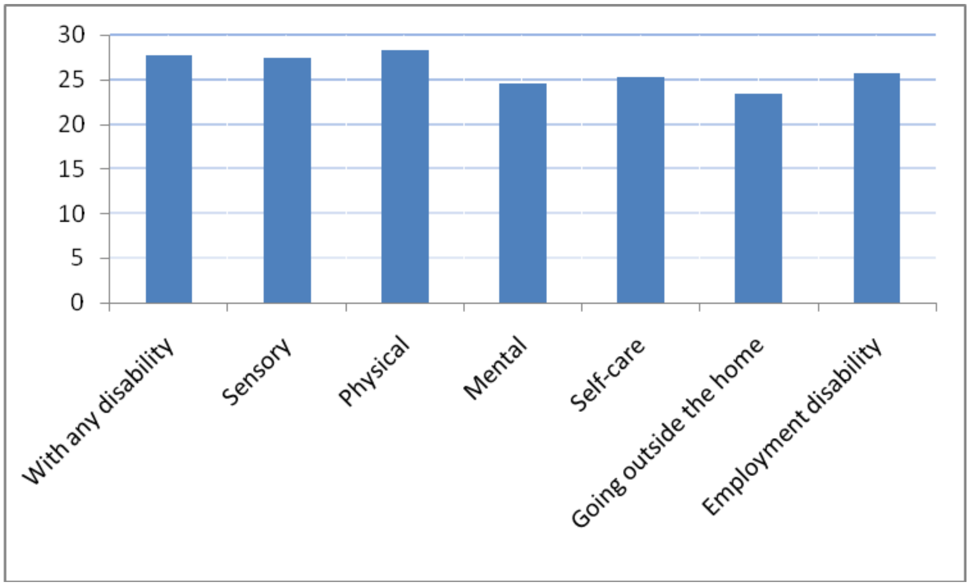


Figure 6: Percentage of disabled with some form of degree (associate or Bachelors or Masters or higher) [14, 15]

1.3 **Motion Study**

Motion Study is the study of body motions involved in a doing a particular task. The Institute of Industrial Engineers (IIE) defines motion study as "The study of basic divisions of work involved in the performance of an operation for the purpose of eliminating all useless motions and arranging the remaining motions in the best sequence for performing the operation" Work Design and Measurement Terminology Z94.17) [16].

In doing any task, there are some effective movements that are some unavoidable involved. But the aim of a motion study is to eliminate the inefficient movements while trying to shorten the efficient movements. The table consists of list of tasks that are considered effective and ineffective.

All work can be considered as a combination as a combination of 17 basic motions called therbligs (reverse of Gilberth who did pioneering work in this area). The Institute of Industrial Engineers defines Therbligs as “A short manual work segment used to describe the sensory-motor activities or other basic elements of an operation”[16]. Therbligs can be effective or ineffective. While the effective therbligs advance the progress of work, ineffective therbligs do not advance work and should be eliminated if possible.

Effective Therblings		**(Diretly advance progress of work. May be shortened but difficult to eliminate)**
Therblig	**Symbol**	**Description**
Reach	RE	Motion of empty hand to or from object; Time depends on distance
Move	M	Movement of loaded hand; Time depends on distance, weight and type of move
Grasp	G	Closing finger around an object; depends on type of grasp
Release	RL	relinquishing Control of objest
Use	U	Manipulating tool for intended use
Assemble	A	Bringing two mating parts together
Disassemble	DA	Opposite of assembly; Seperating mating parts
Pre Position	PP	Positioning object in predetermined location for later use

Ineffective Therblings		**(Do not advance progress of work. Must be eliminated if possible)**
Therblig	**Symbol**	**Description**
Search	S	Eyes or hands groping for object
Select	SE	Choosing one item from Several
Inspect	I	Comparing object with standard
Plan	PL	Pausing to determine next activity
Unavoidable delay	UD	Beyond operators control due nature of the operation
Avoidable delay	D	Operator solely responsible for idle time
Position	PL	Orienting object during work
Rest to overcome fatigue	R	Appears periodically and is not cyclical
Hold	H	One hand supports object while other does useful work

Figure 7: List of Therbligs (Neibel, B., & Freivalds, A., *Methods, Standards & Work Design)*[9]

1.3.1 Time Study

Time study is the process of establishing time standards for various tasks. The IIE defines time study as “work measurement technique consisting of careful time measurement of the task with a time measuring instrument, adjusted for any observed variance from normal effort or pace and to allow adequate time for such items as foreign elements, unavoidable or machine delays, rest to overcome fatigue, and personal needs" (IIE Work Design and Measurement Terminology Z94.17) [16].

Accurate standards are required to complete tasks within the normal time and hence help improve productivity. They are useful in determining labor rates also. The elements that help in time study are: estimates, historic data and work measurement procedures.

Estimation was used in earlier times but it is a technique based more on judgment rather than on facts. With Historic records method, standards are based on the data from similar jobs performed earlier. This method gives standards based on times that earlier jobs actually took rather than the time that it should have taken.

The Institute of Industrial Engineers defines Work measurement as "generic term to refer to the setting of time standard by a recognized engineering technique, such as time study, work sampling, or predetermined motion time systems" (IIE Work Design and Measurement Terminology Z94.17) [16]. Work measurement techniques such as stopwatch time study, video-tape analysis, fundamental motion study or work sampling techniques provide better results. All these techniques are not judgment based and they take the normal time taken for completion in account.

1.3.2 Fair Days Work

The time standards are used in determining Fair Days Work. An employee is entitled to a fair days pay in return for which the company is entitled to a fair days work from the employee [9]. It can be defined as

“Amount of work that can be produced by a qualified employee when working at a normal pace and effectively utilizing his time where work is not restricted by process limitation” [9] .

Here a couple of terms need further elaboration. A qualified employee is one who is fully trained and is able to satisfactorily perform all phases of the work involved. Normal pace is defined as the effective pace of performance of a qualified employee when not working at a fast or slow pace.

1.3.3 Work Standard

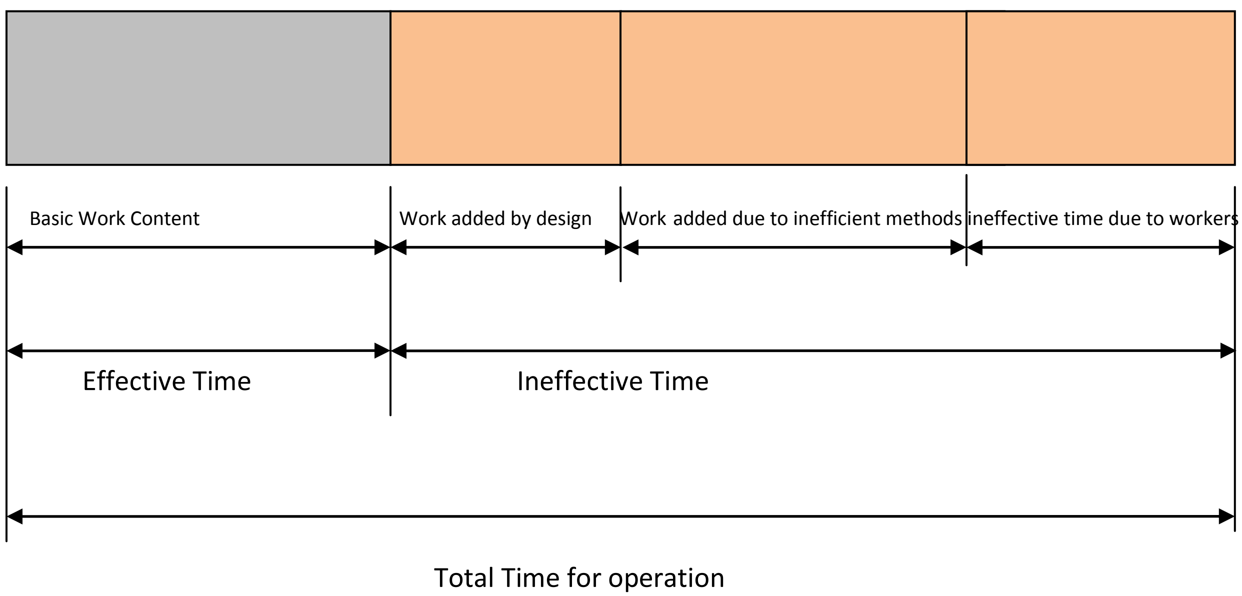


Figure 8: Effective and ineffective time involved in an operation[9]

The figure 8 shows the components of time involved in an operation. The total time is the sum of the effective and ineffective time involved in the operation. The basic work time is the actual time taken if all the design and specifications are perfect and if all the processes involved are fully efficient. It is defined by ILO as the “irreducible minimum time theoretically involved to produce one unit of the product” [3].

The excess or ineffective work content is because of the following:

- Work content added due to poor design or specification of product or its parts or improper utilization of material; this includes poor design, design changes, material wastage, quality issues etc
- Work content due to poor or inefficient manufacturing methods or operations; this includes poor layout, inefficient material handling, bad inventory planning etc
- Work content resulting from human resources; this includes leave, absenteeism etc

1.3.4 Allowances

The IIE defines allowances as "a time value or percentage of time by which the normal time is increased, or the amount of non-productive time applied to compensate for justifiable causes or policy requirements. Usually includes irregular elements, incentive opportunity on machine controlled time, minor unavoidable delays, rest time to overcome fatigue, and time for personal needs" (IIE Work Design and Measurement Terminology Z94.17) [16].

The standard time is the sum of the basic normal time and the allowances added to it. It is important that allowances are added before specifying the standard time. Allowances are required to cover for various factors that could arise during an operation. These factors can be broadly classified as:

- Factors related to individuals such as recovery from fatigue and stress, learning curve etc
- Factors related to the work such as wearing protective clothing before work, delay with machines etc

- Factors related to environment such as heat, humidity, lighting etc

- It is quite a difficult process to allocate allowances that are neither less nor high. In fact ILO recommends that allowances be allocated based on individual cases and that it does not mention any universal system to calculate allowance

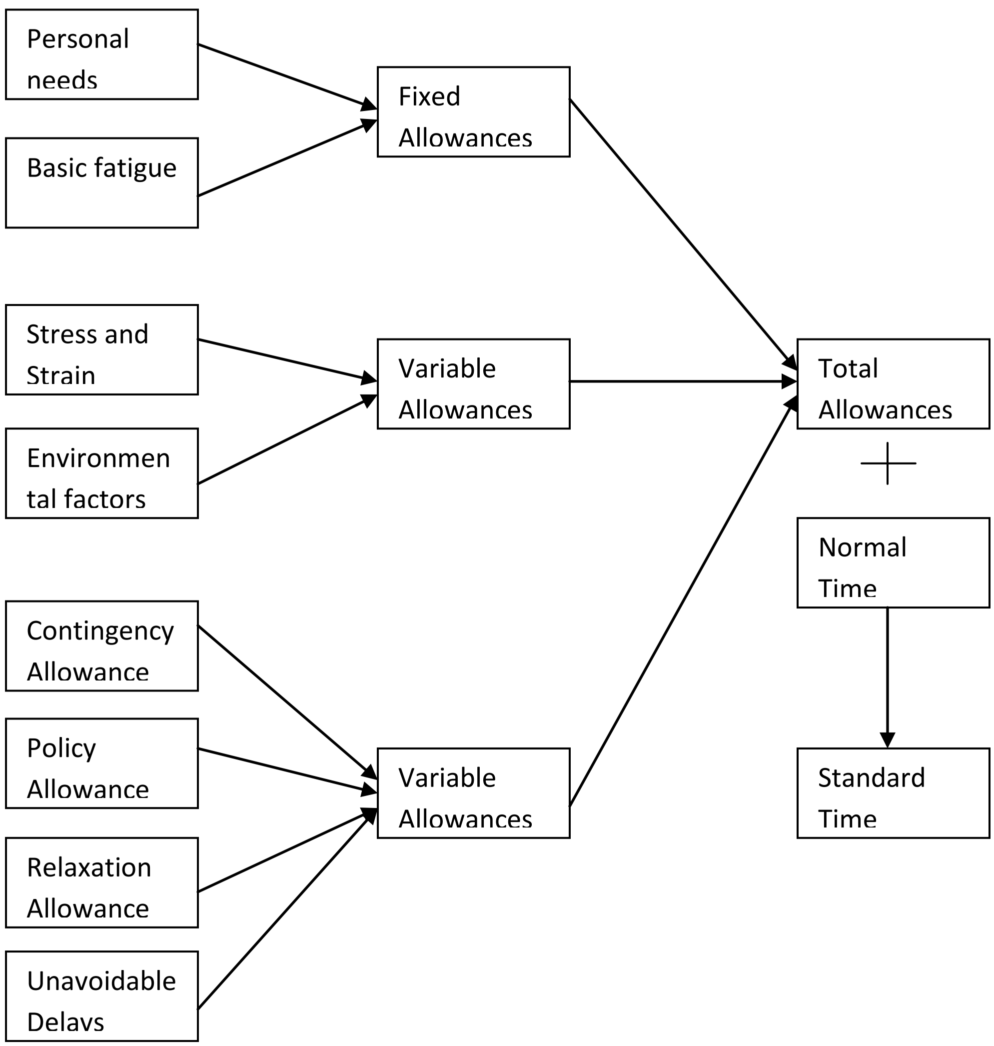


Figure 9: Allowances that make up the total standard time [3]

2. Literature Review

Today protecting the rights of the disabled is one of important goals of all the governments. But this has not always been the case. Till the end of the first half of 20th century, very little action was taken by the governments to protect and help the disabled. There was very little research done in the areas of disability and rehabilitation studies. All this changed during the later half of the last century when awareness regarding the plight of the disabled began to grow. Today a lot of work has been done in the Universities with regards to disability and rehabilitation studies. Due to the efforts of different groups and individuals various laws have been passed to support the disabled at work and other public places. Some of them have been mentioned in the table below.

Table 3: List of legislations made regarding disability welfare in USA (Partly adapted from Subramanian 2007[13] and US government websites on information regarding OSHA[18], ADA[17] and other acts on disability [19])

1. Occupational Safety and Health Act of 1970	To assure safe and healthful working conditions for working men and women; by authorizing enforcement of the standards developed under the Act; by assisting and encouraging the States in their efforts to assure safe and healthful working conditions; [18]
2. ADA of 1990	The ADA prohibits discrimination on the basis of disability in employment, State and local government, public accommodations, commercial facilities, transportation, and telecommunications [17].

3. The Family and Medical Leave Act,	The Family and Medical Leave Act provide certain employees with up to 12 weeks of unpaid, job-protected leave per year. The FMLA is designed to help employees balance their work and family responsibilities by taking reasonable unpaid leave for certain family and medical reasons [19].
4. Rehabilitation Act	The Rehabilitation Act prohibits discrimination on the basis of disability in programs conducted by Federal agencies, in programs receiving Federal financial assistance, in Federal employment, and in the employment practices of Federal contractors [17]
5. Individuals with Disabilities Education Act	The Individuals with Disabilities Education Act (IDEA) (formerly called P.L. 94-142 or the Education for all Handicapped Children Act of 1975) requires public schools to make available to all eligible children with disabilities a free appropriate public education in the least restrictive environment appropriate to their individual needs[17]
6. Air Carrier Access Act	The Air Carrier Access Act prohibits discrimination in air transportation by domestic and foreign air carriers against qualified individuals with physical or mental impairments [17].
7. Architectural Barriers Act	The Architectural Barriers Act (ABA) requires that buildings and facilities that are designed, constructed, or altered with Federal funds, or leased by a Federal agency, comply with Federal standards for physical accessibility [17].

2.1 Need to Develop Modifiers

In this era of great competition, it is important for companies to extract fair day's work from their employees in return for a fair days pay. This goal can be achieved through the standards that have already been developed. Work standard for a task is the time taken to perform the task by a qualified worker performing at a normal pace under normal conditions. But when people with disabilities perform the task, it is clearly not performed under normal conditions.

Some of the earlier research done on specific disabilities and how they affect time taken to perform tasks clearly shows that these standard times cannot be applied when there are disabilities involved. M.F. Reneman, R. Soer and E.H.J. Gerrits designed a Functional Capacity Evaluation (FCE) experiment to show the reduction in work-related functional capacity in patients with Upper Limb Disorders (WRULD) [11]. Pennathur and Mital[7] performed experiments related to finger disabilities to show a reduction in performance while performing dexterity tasks. Hence it is clear that there is a change in level of performance that can be associated with certain disabilities.

Table 4: Physical Domain of Functional Constructs Taxonomy (Adapted from Matheson 2003 [5] and Subramanian [13])

Conceptul Factor	Construct	Definition
Hand Use	Hand range of motion	Ability to move the hands through full range of motion
	Hand Sensitivity	Ability to use hands to sense touch
	Hand Speed	Ability to use the hands in rapid movement
	Hand Coordination	Ability to use hands in a coordinated manner
	Hand Dexterity	Ability to use hands in a coordinated manner
	Hand Endurance	Ability to use hands in a sustained manner
	Eye-Hand Coordination	Ability to coordinate fine movements using visual information
	Manipulating Objects	Ability to seize, hold, grasp or turn objects with hands
Manual Material Handling	Reaching	Ability to stretch arms to grasp or manipulate objects
	Lifting and Lowering	Ability to Lift and Lower objects
	Pushing and Pulling	Ability to push and pull objects
	Carrying Objects	Ability to carry objects while moving

So there is a need to develop modifiers for the standards for people with disabilities. This would involve development of modifiers for each type of disability and for each task. Creating such a database would involve extensive effort into each disability and into each basic task which has not been done so far.

2.2 Prior Research

Earliest research was conducted by Mehta and Mital[6] who conducted experiments to simulate loss of fingers. The disability was the loss of four fingers in preferred hand and loss of thumb in non-preferred hand. The subjects were asked to lift loads to simulate material handling like scenario. They concluded that people with finger disabilities suffered from increased stress while performing handling activities.

Pennathur and Mital[7] performed laboratory investigation on the differences in the functional capabilities of individuals with and without simulated finger disabilities (amputations) when performing routine industrial tasks and standardized strength tests. The disability was the loss of four fingers in preferred hand and loss of thumb in the weaker hand. The subjects were made to perform the Modified Purdue Pegboard Test, O 'Connor Tweezers Dexterity Test, Pennsylvania Bimanual Work Sample Test, and Hand-Tool Dexterity Test. Though there was loss of performance when the tasks were performed with disability, the degree of variation differed based on the type of task.

Table 5: Results from Pennathur –Mital Experiments [7]

(All time in seconds)	Task Time (No disability)	Task Time (Disabled)	Difference	Diff Percentage	Modifier
Modified Purdue Pegboard Test	432	1165	733	169.68%	2.69
O'Connor Tweezer Dexterity Test	453	1172	719	158.72%	2.58
Pennsylvania Bimanual Work Sample	542	542	1575	190.59%	2.9
Hand-Tool Dexterity Test	425	425	723	70.12%	1.7

Table 6: Previous Studies on upper extremities disabilities (adapted and modified from Subramanian 2007 [13])

Experiment / Study	Type of disability	Conclusion
Manual Lifting: Kinematics of disability	Finger	Loss of fingers leads to reduced grip (Mital and Mehta 1988 [6])
The effect of upper extremities posture on maximum grip strength	Hand, arm and shoulder	Reduced grip strength due to one or more disabilities of up to 42% of maximum (Kong et al, 1996 [4])
Comparison of Functional Capabilities of Individuals With and Without Finger Disabilities	Finger	Performance of tasks that required finger dexterity and force exertion adversely affected due to disability, (Pennathur and Mital [7] 1999)
Comparing Severity of Impairment for Different Permanent Upper Extremity Musculoskeletal Injuries	Hand, Arm and Shoulder	Large limitations to the range of motion to the shoulder result in significantly larger reductions in employment and earnings than do injuries to the elbows or wrists. (Reville et al, 2002 [12]).
Basis for an FCE Methodology for Patients with Work-Related Upper Limb Disorders	Upper and Lower arm	Reduced Hand grip strength, Finger Strength, Wrist positioning, hand dexterity (Reneman et al, 2005 [11])
Performance Reduction in Finger Amputees When Reaching and Operating Common Control Devices	Finger	Time taken to operate the control device increased significantly (Pennathur, Mital & Contreras 2001 [8])
Developing MTM Modifiers for tasks performed by individuals with permanent partial disability of fingers	Finger	Developed modifiers for elemental tasks (Subramanian 2007 [13])

Subramanian worked on similar disabilities but aimed to develop modifiers for elemental tasks or therbligs. The disabilities simulated were

- Loss of four fingers in primary/preferred hand only
- Loss of thumb in the non preferred hand only
- Combination both the above mentioned scenarios

The subjects were asked to perform the following tasks

- Large Nut-Bolt assembly
- Medium Nut-Bolt assembly
- Small Nut-Bolt assembly
- Lifting activities

The result of the experiment included the development of modifiers of elemental tasks such as reach, grasp, release etc for each of the disability scenario and for different type of nut-bolt assembly.

3. Methodology

The objective of this thesis work is to develop modifiers for some specific tasks that can be applied to existing standards to develop similar standards for people with disabilities. This thesis continues with the work done by Subramanian [13]. While his work related to assembly related activities, my objective was to verify his simulation conducted for one of the assembly activity (assembly of large Nut-bolt assembly) and to further work on tasks widely used in services and information technology industry such as typing and mouse handling.

The new tasks that were simulated include a typing activity using a keyboard and an activity to draw a small figure that would involve utilization of the mouse. While the typing activity was meant to study the variation of speed of typing as a result of disability, the mouse activity was meant to study the effect of disability on the dexterity of hand.

Hence the broad classification of the activities that were performed included:

1. Dexterity related task which is the large nut-bolt assembly and disassembly task

2. Office related task that includes typing and mouse movement tasks

3.1 Disability Scenarios:

The disability chosen were the same as the one selected by Subramanian so that the modifiers developed for the first activity could be verified with his results so that experiments can be standardized. The disability conditions are

1. Loss of four fingers (except thumb) in the primary hand

2. Loss of thumb in the non-preferred hand

3. A combination ob both the above conditions

In addition to the three disability scenarios, there is the control scenario where volunteers are to complete the tasks without disability. The control scenario is the baseline or basic scenario with which the other scenarios are compared. So the volunteers for all the three tasks were asked to perform the activities under the four scenarios – D00- No disability, D00- Disability of loss of four fingers in primary hand, D00- Disability of loss of thumb in non-preferred hand and D03- Disability of a combination of both the above mentioned scenarios). The data collected for the different scenarios helped compare the time taken for each scenario. This helped in developing the modifiers for different elemental tasks for each of the disability scenario. The following are the pictures of the disability scenarios.

Figure 10: Scenario D01 - Loss of four fingers in the preferred hand

Figure 11: Scenario D02 - Loss of thumb in the non-preferred hand

Figure 12: Scenario D03 - Combination of both the disabilities

3.2 Volunteers

All the volunteers were selected from University of Cincinnati. All the volunteers were between the ages of 22 and 30. They were made to perform the tasks in a clean, well ventilated place without any disturbance from noise. It was made sure that they had no physical disabilities or under any medication. Also each volunteer was explained about the purpose of the experiment, the tasks involved and on how to carry out each task.

The volunteers were trained by making them practice each task. The practice runs made sure that they would be fully trained before the actual experiment. This is in accordance with the theory of learning cure that states that as quantity produced gets doubled, the time taken for single unit reduces by a fixed percentage. This curve is exponential in nature and so with more training gets flatter. Besides they were given adequate time between the tasks.

3.3 Equipment

The key requirement was the modified glove pair that created the condition similar to the disability. The basic gloves were the Craftsmen™ industrial gloves. These are popular among mechanics and other workers as they are very comfortable, light and don't impede with movements in any way as a normal winter gloves would. The gloves were cut as required and taped. The Velcro helped to keep the gloves in place as required and helped simulate the disability. Care was taken to make sure that tightening effect provided by the Velcro did not affect the ability of the volunteers to perform their tasks.

The figure shows the set-up of the assembly activity. The setup includes a wooden board with provisions for carry out the assembly and disassembly activities. The volunteers were asked to assemble and disassemble 4 large nut-bolt setups. So each nut-bolt assembly consists of a large nut, large bolt and a pair of washers. The tools included adjustable wrenches that were used in assembly and disassembly activities.

Figure 13: Equipment used in experiments

The typing task set-up included a standard IBM-Lenovo ™ keyboard and a clipboard with the text that the volunteers could place at any convenient location. The mouse activity was carried out using a standard Sony mouse that was plugged to a computer. Both the tasks were performed using the Microsoft Office 2007® software that was run on the Microsoft Windows XP® platform. The hardware included a 14” screen and a system with 512 MB RAM and 1.7 GHz processing speed.

All the experiments were recorded using the video camera as mentioned in the previous section. This was to make sure that analysis can be made on a frame to frame basis. As a frame would be one thirtieth of a second, this method ensures great accuracy. Also it helps to get back and reanalyze the tapes in case there are any about the data points.

The following figure gives the layout used for the assembly activity. The layout shows the position of subject, the test board, the tools placed at B and the location of nuts, bolts and washer at A. The distances have also been shown. This is similar to the setup used by Subramanian[13] to complete his experiments as the objective of this experiment was to validate or verify his results.

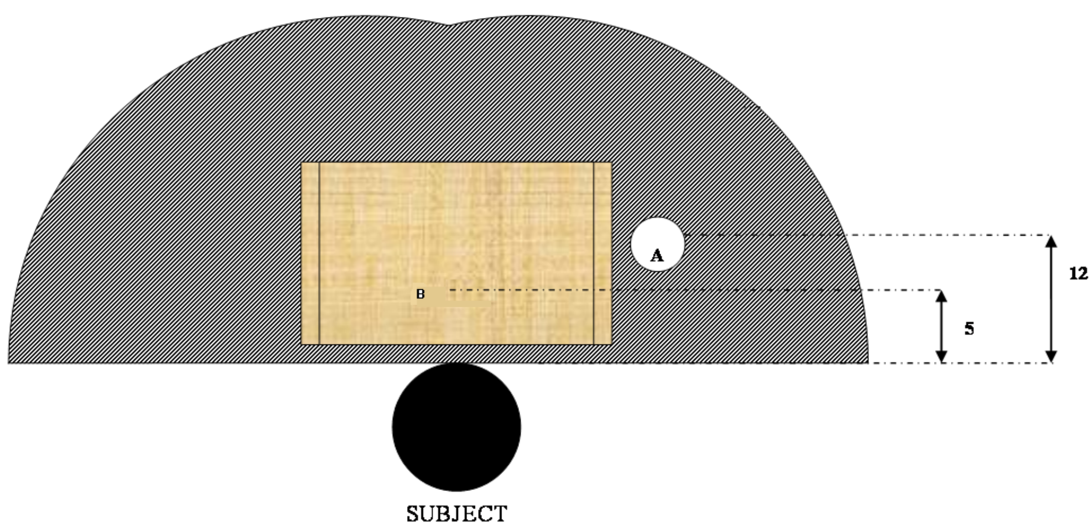


Figure 14: Layout of the assembly experiment (adapted and modified from Subramanian 2007 [13]**)**

3.4 Experimental Tasks

3.4.1 Assembly Activity

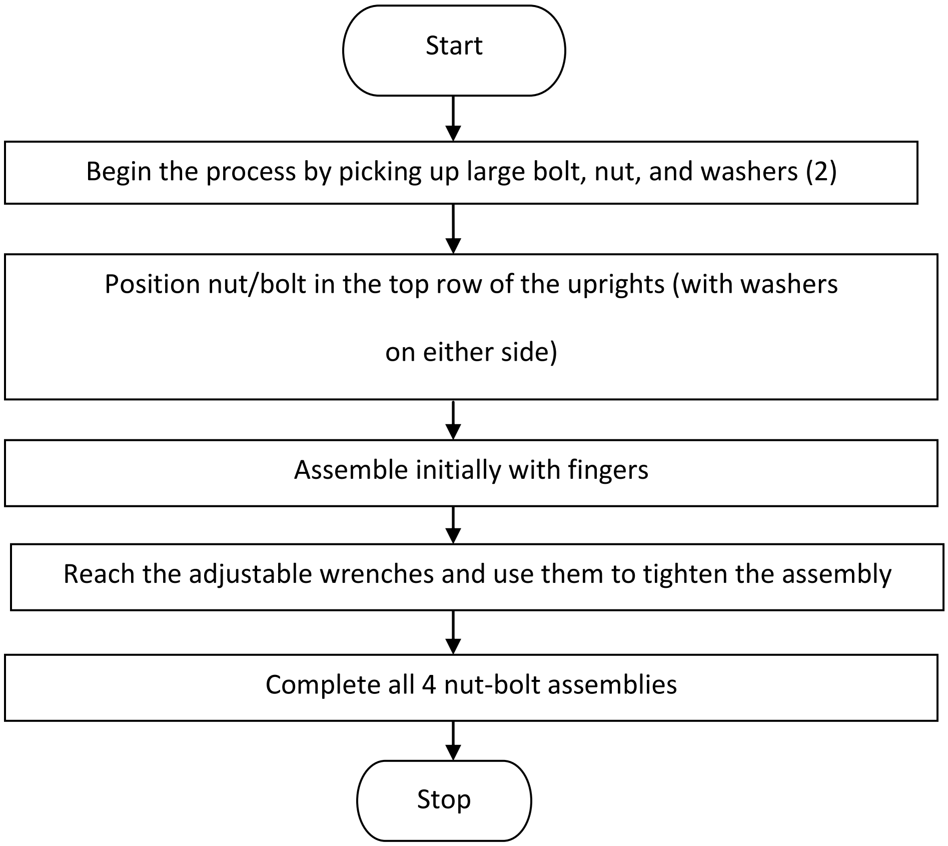


Figure 15 A: Flowchart representing the assembly activity

3.4.2 Disassembly Activity

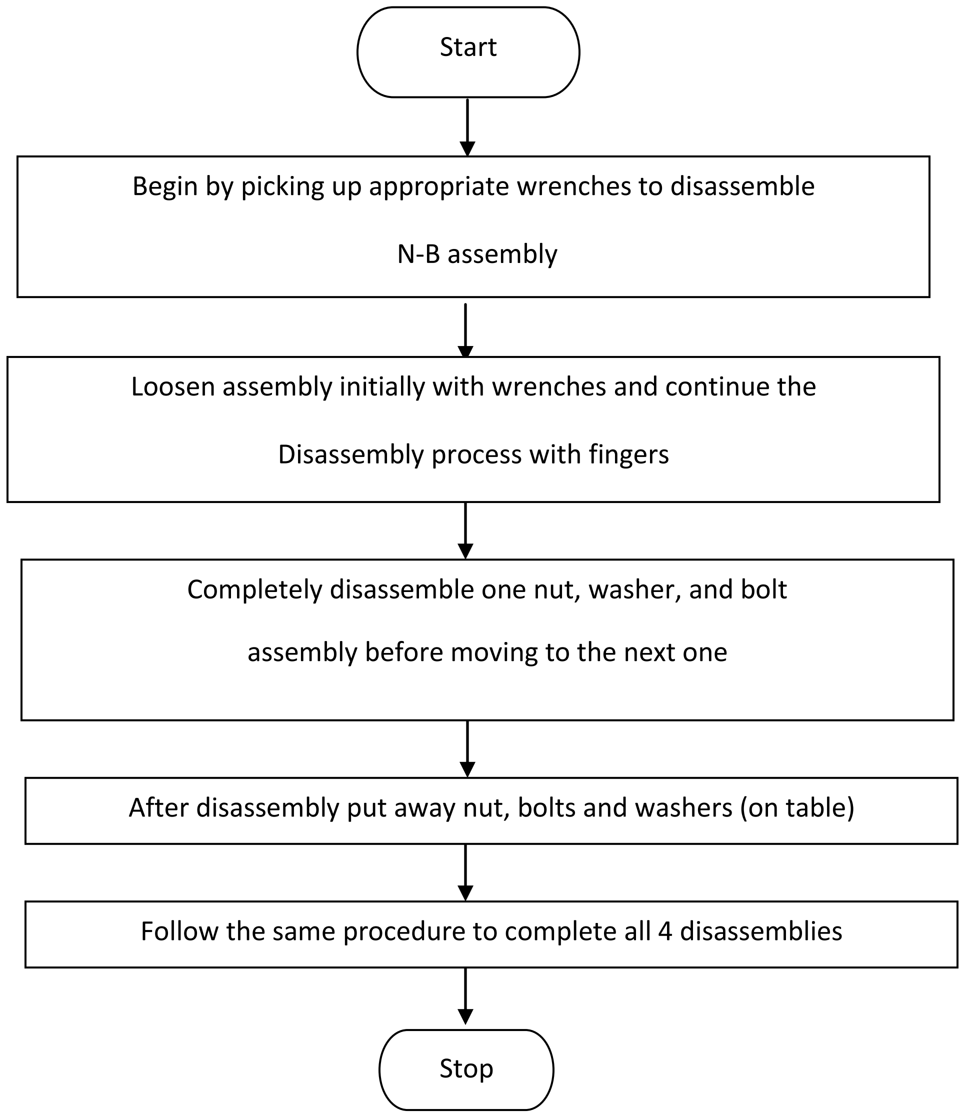


Figure 15 B: Flowchart showing the disassembly activity

3.4.3 Typing Activity Text

RFID stands for Radio-Frequency Identification. The acronym refers to small electronic devices that consist of a small chip and an antenna. The chip typically is capable of carrying 2,000 bytes of data or less.

The RFID device serves the same purpose as a bar code or a magnetic strip on the back of a credit card or ATM card; it provides a unique identifier for that object. RFID needs a scanner device to retrieve the information present in them. RFID technology is widely used in asset tracking (such as pallets), retail industry such as in Wal-Mart and in medical applications.

3.4.4 Drawing Task

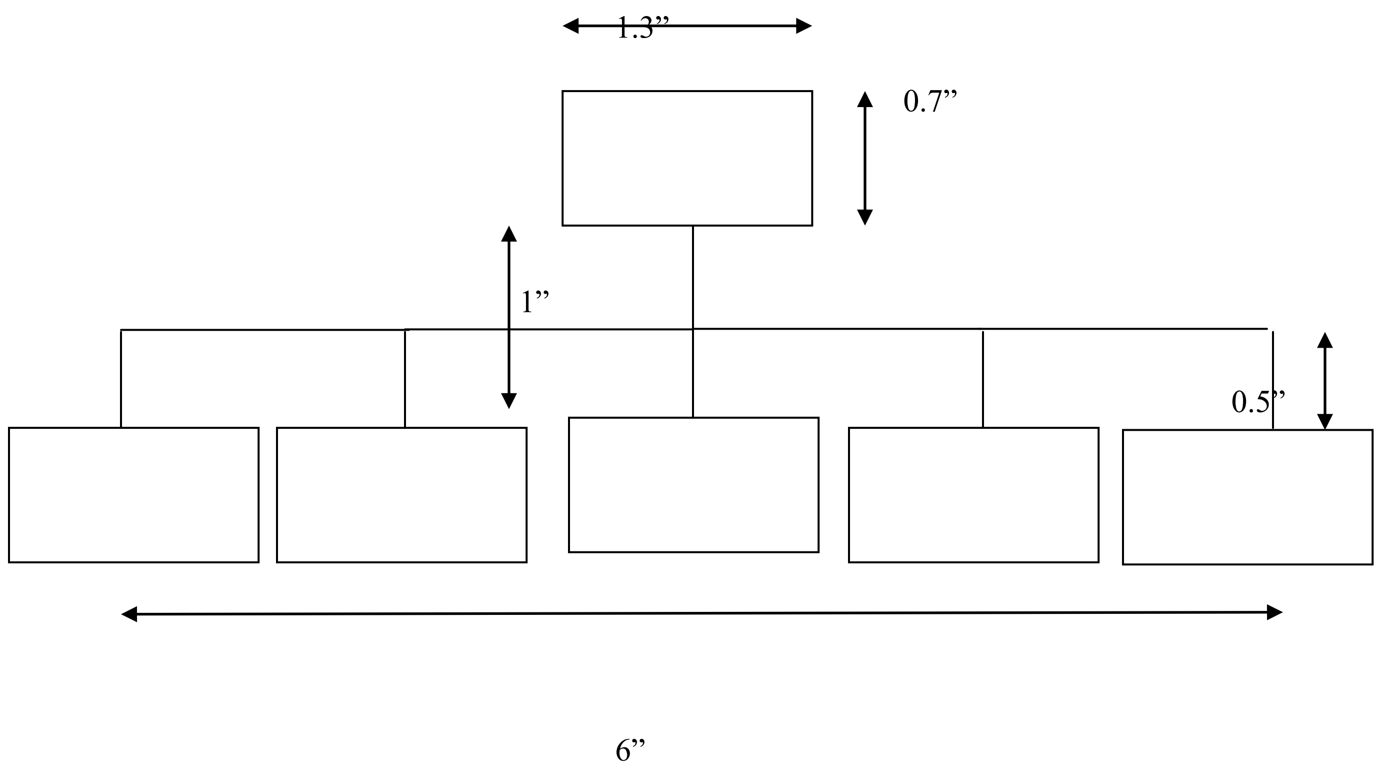


Figure 16: Drawing task

Table 7: Description of Start and End points for tasks (Adapted and modified from Subramanian 2007 [13])

Activity	**Start Point**	**End Point**
Reach N-B	First limb movement to reach the Nut/bolt/washer	Limb completely extended to reach the Nut/bolt/washer or first touch of Nut/Bolt/Washer
Grasp N-B	Limb movement to reach the location of Nut/bolt/washer or end of reach activity	Limbs begin to move away after picking or grasping the Nut/bolt/washer
Move N-B	Limb movement (retraction) after picking	Limb reaches the final location or location of assembly
Position N-B	Limb movement to reach the final position of end of move activity	Bolt /washer (1) combination pass through the hole in the board
Assemble N-B hands	Subject starts to assemble washer nut assembly or end of position activity	Subjects begin to move limb to reach for tools after completing assembly with hands
Reach tool	First limb movement to reach the tool	Limb completely extended to reach the tool or first touch of tool
Grasp tool	Limb movement to reach the location of tool or first touch of the tool	Limbs begin to move away after picking the tool
Move tool	Limb movement (retract) after picking up the tool	Limb reaches the final location or location of assembly
Assemble N-B tools	Subject reach the location of assembly	Subjects begin to move limb away from assembly
Release Tool	Limbs have stopped moving after reaching the drop point for tools	Last touch of tools or hands starts moving away
Disassemble N-B tools	Subject reach the location of the assembly	Subjects begin to move limb away from assembly

Disassemble N-B hands	Subject reach the location of the assembly	Subjects begin to move limb away from assembly after dismantling the nut-bolt assembly
Release Tool	Limbs have stopped moving after reaching the drop point for nuts	Last touch of nuts/bolts or hands starts moving away
Typing	Limb movement towards the keyboard / first touch of keyboard	Start of Limb movement away from keypad
Mouse action to reach "draw" Mouse Movement	Limb movement to start movement of mouse	Limb movement to reach the end point

Table 8: Standard MTM times[13]

Task	Task	PMTS Code	TMUs	Standard Time (sec)
Large Bolt Assembly	Reach Large N-B	R12B	12.9	0.534
	grasp N-B	G1A	2	0.083
	move N-B	M12A	12.9	0.534
	Position N-B	P1SE	5.6	0.232
	Reach Large tool	R5B	7.8	0.323
	Grasp Large tools	G1A	2	0.083
	Move Large tools	M5A	7.3	0.302
	Release Large tools	RL1	2	0.083
Large Bolt Disassembly	Reach Large tools	R5B	7.8	0.323
	Release Large Tools	RL1	2	0.083
	Move Large N-B	M10A	11.3	0.468
	Relase Large N-B	RL1	2	0.083

3.5 Statistical Analysis

All the tasks were videotaped using a standard video camera and the taped were analyzed using the same camera connected to a television. The start and end points were noted based on the definitions specified in table 5. The difference between them gave the time taken for each task which was noted in the spreadsheet. One of the advantages of videotape analysis is that a high degree of accuracy (± 2 frames and each frame equals one thirtieth of a second) could be maintained and the delays could be excluded from actual time taken for each elemental task.

The start and end times for each task were noted in excel® sheet. Then formulas were entered to get the difference in frames, seconds and minutes that would give the actual time taken for each task. This is done for each task and for each disability scenario. Then the major parameters such as mean, median, standard deviation were calculated and have been tabulated.

With the parameters in hand, normality tests (Shapiro-Wilk) and t-tests (with data from Subramanian's experiments) were done using Analyze-IT® add-in with Microsoft Excel®. Then modifiers were developed using the data from the experiments. Also similar procedure was followed to identify the modifiers for the typing and mouse drawing tasks.

4. Results

As mentioned before, based on the values obtained from the video tape analysis, the time taken for individual tasks is found out and tabulated. With these values, statistical parameters such as mean, median and standard deviation were calculated. These tables have been added in the following pages.

Based on the values, the percentage variation and modifiers were calculated. These values have been included in the following tables.

Table 9: Summary statistics for elemental tasks in large bolt assembly under Control-D00 condition

	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean	0.449	0.380	1.088	0.538	0.409	0.241	0.679	0.148
Median	0.433	0.367	1.067	0.533	0.400	0.233	0.700	0.133
SD	0.088	0.111	0.101	0.119	0.056	0.039	0.134	0.021
Min	0.333	0.233	0.933	0.233	0.300	0.167	0.433	0.133
Max	0.700	0.700	1.400	0.733	0.533	0.300	0.933	0.200
0.05	0.367	0.233	0.967	0.367	0.333	0.200	0.472	0.133
0.1	0.367	0.260	0.967	0.400	0.333	0.200	0.500	0.133
0.25	0.400	0.333	1.000	0.467	0.367	0.200	0.592	0.133
0.5	0.433	0.367	1.067	0.533	0.400	0.233	0.700	0.133
0.75	0.492	0.433	1.133	0.667	0.433	0.267	0.767	0.167
0.9	0.567	0.533	1.200	0.700	0.493	0.300	0.833	0.167
0.95	0.600	0.553	1.260	0.700	0.500	0.300	0.890	0.175

	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B
Mean	0.680	0.139	0.582	0.203
Median	0.667	0.133	0.600	0.200
SD	0.0940	0.032	0.060	0.042
Min	0.500	0.100	0.500	0.133
Max	0.867	0.167	0.667	0.300
0.05	0.560	0.100	0.500	0.137
0.1	0.567	0.113	0.500	0.167
0.25	0.600	0.133	0.533	0.167
0.5	0.667	0.133	0.600	0.200
0.75	0.767	0.150	0.633	0.233
0.9	0.813	0.167	0.663	0.267
0.95	0.833	0.167	0.667	0.267

Table 10: Summary statistics for elemental tasks in large bolt assembly under Control-D01 condition

	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean	0.460	0.425	1.107	0.574	0.440	0.531	0.678	0.147
Median	0.433	0.433	1.100	0.567	0.433	0.500	0.667	0.133
SD	0.089	0.074	0.107	0.109	0.063	0.080	0.099	0.039
Min	0.267	0.300	0.900	0.400	0.300	0.400	0.467	0.000
Max	0.667	0.567	1.333	0.867	0.567	0.733	0.900	0.200
0.05	0.333	0.333	0.967	0.400	0.333	0.400	0.533	0.100
0.1	0.367	0.333	0.967	0.420	0.340	0.433	0.567	0.107
0.25	0.400	0.367	1.033	0.500	0.400	0.475	0.600	0.133
0.5	0.433	0.433	1.100	0.567	0.433	0.500	0.667	0.133
0.75	0.500	0.500	1.167	0.667	0.500	0.592	0.725	0.167
0.9	0.600	0.520	1.267	0.700	0.500	0.643	0.810	0.200
0.95	0.633	0.533	1.300	0.707	0.513	0.667	0.872	0.200

	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B
Mean	0.669	0.144	0.604	0.221
Median	0.700	0.133	0.600	0.217
SD	0.106	0.032	0.076	0.056
Min	0.500	0.100	0.467	0.133
Max	0.833	0.233	0.767	0.367
0.05	0.500	0.100	0.485	0.133
0.1	0.513	0.100	0.500	0.157
0.25	0.567	0.133	0.567	0.175
0.5	0.700	0.133	0.600	0.217
0.75	0.733	0.167	0.667	0.267
0.9	0.800	0.167	0.700	0.300
0.95	0.800	0.195	0.715	0.300

Table 11: Summary statistics for elemental tasks in large bolt assembly under Control-D02 condition

	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean	0.459	0.413	1.080	0.570	0.410	0.474	0.662	0.152
Median	0.467	0.383	1.067	0.567	0.400	0.433	0.667	0.133
SD	0.088	0.179	0.112	0.141	0.047	0.154	0.087	0.029
Min	0.300	0.200	0.900	0.267	0.333	0.300	0.467	0.100
Max	0.633	0.833	1.300	0.833	0.500	0.900	0.833	0.200
0.05	0.310	0.200	0.933	0.353	0.333	0.300	0.505	0.128
0.1	0.333	0.203	0.967	0.373	0.343	0.333	0.543	0.133
0.25	0.400	0.267	1.000	0.433	0.367	0.367	0.600	0.133
0.5	0.467	0.383	1.067	0.567	0.400	0.433	0.667	0.133
0.75	0.533	0.492	1.167	0.667	0.433	0.500	0.733	0.167
0.9	0.567	0.667	1.233	0.727	0.467	0.727	0.767	0.200
0.95	0.600	0.795	1.233	0.780	0.467	0.767	0.767	0.200

	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B
Mean	0.699	0.140	0.593	0.217
Median	0.717	0.133	0.600	0.233
SD	0.101	0.049	0.108	0.036
Min	0.533	0.000	0.333	0.133
Max	1.000	0.200	0.767	0.267
0.05	0.538	0.065	0.440	0.167
0.1	0.577	0.110	0.473	0.167
0.25	0.633	0.133	0.500	0.200
0.5	0.717	0.133	0.600	0.233
0.75	0.733	0.167	0.667	0.233
0.9	0.790	0.190	0.733	0.267
0.95	0.828	0.200	0.733	0.267

Table 12: Summary statistics for elemental tasks in large bolt assembly under Control-D03 condition

	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean	0.452	0.553	1.090	0.595	0.417	0.583	0.671	0.149
Median	0.433	0.567	1.067	0.600	0.417	0.567	0.700	0.133
SD	0.078	0.130	0.115	0.130	0.058	0.118	0.136	0.021
Min	0.300	0.200	0.900	0.333	0.300	0.400	0.300	0.133
Max	0.600	0.833	1.333	0.867	0.533	0.800	0.867	0.200
0.05	0.333	0.333	0.952	0.387	0.333	0.400	0.460	0.133
0.1	0.367	0.400	0.967	0.433	0.367	0.433	0.493	0.133
0.25	0.400	0.492	1.000	0.533	0.367	0.500	0.583	0.133
0.5	0.433	0.567	1.067	0.600	0.417	0.567	0.700	0.133
0.75	0.500	0.642	1.142	0.667	0.467	0.625	0.783	0.167
0.9	0.567	0.700	1.293	0.793	0.483	0.767	0.833	0.167
0.95	0.567	0.737	1.315	0.833	0.508	0.800	0.833	0.177

	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B
Mean	0.694	0.133	0.586	0.217
Median	0.667	0.133	0.600	0.200
SD	0.129	0.047	0.095	0.054
Min	0.500	0.000	0.333	0.133
Max	0.967	0.167	0.767	0.333
0.05	0.522	0.067	0.467	0.167
0.1	0.543	0.133	0.500	0.167
0.25	0.608	0.133	0.500	0.167
0.5	0.667	0.133	0.600	0.200
0.75	0.758	0.167	0.667	0.250
0.9	0.890	0.167	0.733	0.280
0.95	0.945	0.167	0.733	0.323

Table 13: Mean times for elemental tasks and dexterity tasks

Task	D00	D01	D02	D03
Reach Large N-B	0.4498	0.460	0.459	0.452
grasp N-B	0.3800	0.425	0.413	0.553
move N-B	1.088	1.107	1.080	1.090
Position N-B	0.5379	0.574	0.570	0.595
Reach Large tool	0.4090	0.440	0.410	0.417
Grasp Large tools	0.2410	0.531	0.474	0.583
Move Large tools	0.6792	0.678	0.662	0.671
Release Large tools	0.1480	0.147	0.152	0.149
Reach Large tools	0.681	0.669	0.699	0.694
Release Large Tools	0.139	0.144	0.140	0.133
Move Large N-B	0.582	0.604	0.593	0.586
Relase Large N-B	0.203	0.221	0.217	0.217
Assemble tool	4.313	4.688	4.739	6.768
Assemble hand	8.138	9.116	8.432	11.918
Disassemble hand	6.955	7.371	7.159	8.724
Disassemble tool	5.140	6.085	5.310	6.458

The following table gives the percentage variation for Scenario's D01, D02 and D03 over scenario D00. A cut-off of 5% was used to judge if the variation was significant or not. It can be clearly seen that for tasks such as reach, move the variation is quite low. But for some of the other tasks the impact of the disabilities has been much bigger.

Table 14: Percentage variation (absolute) for scenario D01, D02 and D03

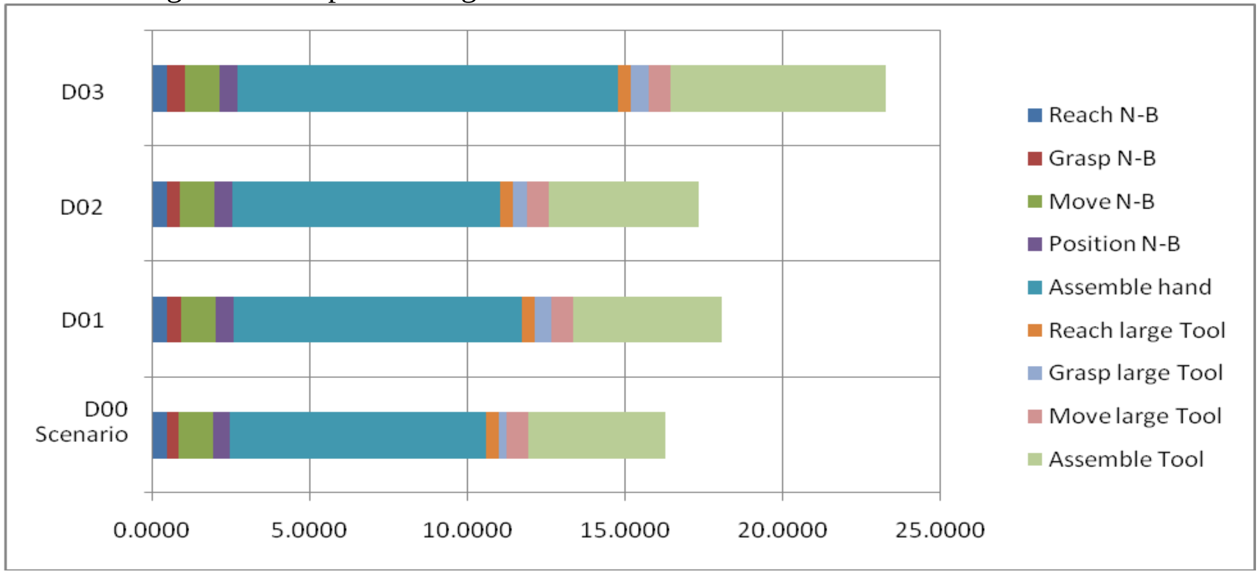
Task	D01	D02	D03
Reach Large N-B	2.278	2.055	0.499
grasp N-B	11.842	8.605	45.526
move N-B	1.746	0.735	0.184
Position N-B	6.709	5.966	10.705
Reach Large tool	7.579	0.244	1.956
Grasp Large tools	120.332	96.572	141.909
Move Large tools	0.158	2.528	1.202
Release Large tools	0.676	2.703	0.676
Reach Large tools	1.711	2.643	1.926
Release Large Tools	3.597	0.719	4.317
Move Large N-B	3.780	1.890	0.687
Relase Large N-B	8.867	6.897	6.897
Assemble tool	8.695	9.877	56.921
Assemble hand	12.018	3.608	46.449
Disassemble hand	5.993	2.939	25.445
Disassemble tool	18.378	3.307	25.642

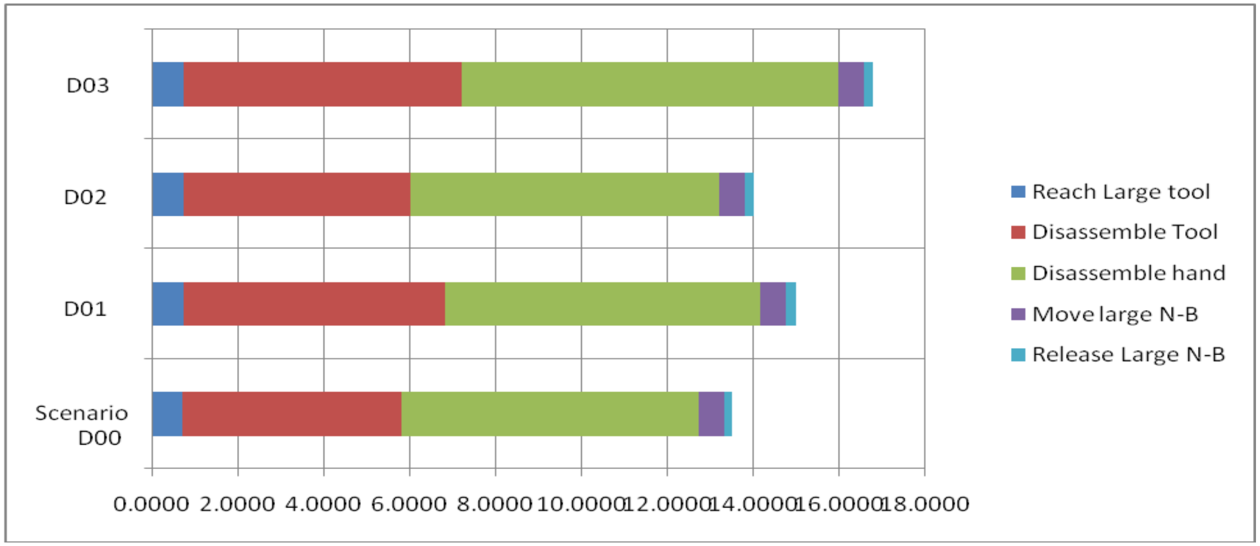
Modifiers have been developed as the ratios of time taken for the task with disability to the time taken for the same task without any disability. Again modifier values close to 1 indicate that the disability has little impact on the time taken to perform that task. One interesting observation is that for tasks like disassemble using tool and hand, modifier value for scenario D02 is close to 1 while other 2 scenarios have higher modifier value. This would mean that disability to non preferred hand has lesser impact than disability to preferred hand for that task.

Table 15: Modifiers for Scenarios D01, D02 and D03

Task	D01	D02	D02
Reach Large N-B	1.02	1.02	1.00
grasp N-B	1.12	1.09	1.46
move N-B	1.02	0.99	1.00
Position N-B	1.07	1.06	1.11
Reach Large tool	1.08	1.00	1.02
Grasp Large tools	2.20	1.97	2.42
Move Large tools	1.00	0.97	0.99
Release Large tools	0.99	1.03	1.01
Reach Large tools	0.98	1.03	1.02
Release Large Tools	1.04	1.01	0.96
Move Large N-B	1.04	1.02	1.01
Relase Large N-B	1.09	1.07	1.07
Assemble tool	1.09	1.10	1.57
Assemble hand	1.12	1.04	1.46
Disassemble hand	1.06	1.03	1.25
Disassemble tool	1.18	1.03	1.26

Figure 17: Graph showing the time taken for each task for the four scenarios





4.1 Comparison of results (With Subramanian's results [13])

Subramanian performed similar experiments (Subramanian A., "Developing MTM modifiers for tasks performed by individuals with permanent partial disability of the fingers", 2007 [13]) and his results have been modified and presented in the following table. It shows the percentage time taken by each scenario with D00 as the base. The next table gives the same calculation for values obtain in author's experiment.

Table 16: Percentage time for Scenario D01, D02 and D03 as compared to D00 (Subramanian 2007 [13])

Task	D00	D01	D02	D03
Reach Large N-B	100.00	101.36	101.59	100.68
grasp N-B	100.00	118.26	115.26	148.23
move N-B	100.00	101.73	99.45	100.82
Position N-B	100.00	102.73	101.28	107.29
Reach Large tool	100.00	107.44	100.25	100.74
Grasp Large tools	100.00	232.62	197.00	258.37
Move Large tools	100.00	99.85	97.75	97.90
Release Large tools	100.00	100.00	105.52	102.07
Reach Large tools	100.00	106.81	100.43	101.56
Release Large Tools	100.00	99.26	98.52	102.22
Move Large N-B	100.00	103.49	101.05	102.97
Relase Large N-B	100.00	104.37	102.91	101.94
Assemble tool	100.00	107.70	109.02	157.09
Assemble hand	100.00	113.40	106.23	151.46
Disassemble hand	100.00	106.23	104.79	127.28
Disassemble tool	100.00	120.49	104.52	129.42

Table 17: Percentage time for Scenario D01, D02 and D03 as compared to D00

Task	D00	D01	D02	D03
Reach Large N-B	100.00	102.28	102.06	100.50
grasp N-B	100.00	111.84	108.60	145.53
move N-B	100.00	101.75	99.26	100.18
Position N-B	100.00	106.71	105.97	110.71
Reach Large tool	100.00	107.58	100.24	101.96
Grasp Large tools	100.00	220.33	196.57	241.91
Move Large tools	100.00	99.84	97.47	98.80
Release Large tools	100.00	99.32	102.70	100.68
Reach Large tools	100.00	98.29	102.64	101.93
Release Large Tools	100.00	103.60	100.72	95.68
Move Large N-B	100.00	103.78	101.89	100.69
Relase Large N-B	100.00	108.87	106.90	106.90
Assemble tool	100.00	108.69	109.88	156.92
Assemble hand	100.00	112.02	103.61	146.45
Disassemble hand	100.00	105.99	102.94	125.45
Disassemble tool	100.00	118.38	103.31	125.64

Table 18: Percentage comparison of all Scenarios (Subramanian's data [13] and author's data with author's D00 as base scenario)

	D00	Subramanian D00	D01	Subramanian D01	D02	Subramanian D02	D03	Subramanian D03
Reach Large N-B	100.00	97.83	102.28	99.16	102.06	99.39	100.50	98.50
grasp N-B	100.00	96.58	111.84	114.21	108.60	111.32	145.53	143.16
move N-B	100.00	101.01	101.75	102.76	99.26	100.46	100.18	101.84
Position N-B	100.00	102.06	106.71	104.85	105.97	103.36	110.71	109.50
Reach Large tool	100.00	98.53	107.58	105.87	100.24	98.78	101.96	99.27
Grasp Large tools	100.00	96.68	220.33	224.90	196.57	190.46	241.91	249.79
Move Large tools	100.00	98.21	99.84	98.06	97.47	96.00	98.80	96.15
Release Large tools	100.00	97.97	99.32	97.97	102.70	103.38	100.68	100.00
Reach Large tools	100.00	103.52	98.29	110.57	102.64	103.96	101.93	105.14
Release Large Tools	100.00	97.12	103.60	96.40	100.72	95.68	95.68	99.28
Move Large N-B	100.00	98.45	103.78	101.89	101.89	99.48	100.69	101.37
Relase Large N-B	100.00	101.48	108.87	105.91	106.90	104.43	106.90	103.45
Assemble tool	100.00	101.81	108.69	109.65	109.88	110.99	156.92	159.94
Assemble hand	100.00	98.96	112.02	112.21	103.61	105.12	146.45	149.88
Disassemble hand	100.00	99.93	105.99	106.16	102.94	104.72	125.45	127.20
Disassemble tool	100.00	98.48	118.38	118.66	103.31	102.94	125.64	127.45

Normality tests and T tests were performed to show that Subramanian's [13] and author's samples were similar. This was performed using the Excel® software. Once these tests showed that samples were identical, the samples were combined to create a larger sample. Using this sample, modifiers were calculated.

In the following tables (17-20), Mean 1 stands for mean from current data while mean 2 stands for mean from Subramanian's data [13].

Table 19 Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D00 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean 1	0.4498	0.3800	1.088	0.5379	0.4090	0.2410	0.6792	0.1480
Mean 2	0.4400	0.3670	1.0990	0.5490	0.4030	0.2330	0.6670	0.1450
Pooled Variance	0.0042	0.0064	0.0074	0.0077	0.0019	0.0025	0.0137	0.0049
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Task	Reach Large tools	Release Large Tools	Move Large N-B	Relase Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Mean 1	0.6810	0.1390	0.5820	0.2030	4.3130	8.1380	6.9546	5.1400
Mean 2	0.7050	0.1350	0.5730	0.2060	4.3910	8.0530	6.9500	5.0620
Pooled Variance	0.0192	0.0005	0.0128	0.0010	0.3816	1.2109	0.4064	0.2129
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 20: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D01 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean 1	0.460	0.425	1.107	0.574	0.4400	0.5310	0.6781	0.1470
Mean 2	0.4460	0.4340	1.1180	0.5640	0.4330	0.5420	0.6660	0.1450
Pooled Variance	0.0067	0.0031	0.0083	0.0083	0.0027	0.0038	0.0104	0.0008
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Task	Reach Large tools	Release Large Tools	Move Large N-B	Relase Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Mean 1	0.669	0.144	0.604	0.221	4.6880	9.1160	7.3714	6.0846
Mean 2	0.7530	0.1340	0.5930	0.2150	4.7290	9.1320	7.3830	6.0990
Pooled Variance	0.0252	0.0055	0.0130	0.0023	0.4191	0.7476	0.4178	0.8541
Acceptable	NO	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 21: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D02 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean 1	0.459	0.413	1.080	0.570	0.4100	0.4737	0.6620	0.1520
Mean 2	0.4470	0.4230	1.0930	0.5560	0.4040	0.4590	0.6520	0.1530
Pooled Variance	0.0048	0.0163	0.0099	0.0109	0.0022	0.0123	0.0083	0.0004
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Task	Reach Large tools	Release Large Tools	Move Large N-B	Relase Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Mean 1	0.699	0.140	0.593	0.217	4.7390	8.4316	7.1590	5.3100
Mean 2	0.7080	0.1330	0.5790	0.2120	4.7870	8.5550	7.2830	5.2910
Pooled Variance	0.0127	0.0016	0.0127	0.0014	0.5704	0.8006	0.5156	0.1747
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 22: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D03 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Mean 1	0.452	0.553	1.090	0.595	0.4170	0.5830	0.6710	0.1490
Mean 2	0.4430	0.5440	1.1080	0.5890	0.4060	0.6020	0.6530	0.1480
Pooled Variance	0.0064	0.0121	0.0137	0.0127	0.0038	0.0144	0.0163	0.0009
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Task	Reach Large tools	Release Large Tools	Move Large N-B	Relase Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Mean 1	0.694	0.133	0.586	0.217	6.7680	11.9180	8.7242	6.4580
Mean 2	0.7160	0.1380	0.5900	0.2100	6.8980	12.1970	8.8460	6.5510
Pooled Variance	0.0316	0.0015	0.0551	0.0021	0.8703	3.5052	0.7936	0.6450
Acceptable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

4.2 Combined Data

After making sure that the samples were similar, the samples were combined. The means were combined and the variances were pooled. The combining of the means gave the advantage of the higher sample space than the individual samples.

Table 23: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D00 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Aswin's Mean	0.4498	0.3800	1.0880	0.5379	0.4090	0.2410	0.6792	0.1480
Anand's Mean	0.4400	0.3670	1.0990	0.5490	0.4030	0.2330	0.6670	0.1450
Pooled Var	0.0042	0.0064	0.0074	0.0077	0.0019	0.0033	0.0137	0.0049
Pooled SD	0.0651	0.0802	0.0860	0.0876	0.0431	0.0571	0.1172	0.0702
Combined Mean	0.4449	0.3735	1.0935	0.5435	0.4060	0.2370	0.6731	0.1465

Task	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Aswin's Mean	0.6810	0.1390	0.5820	0.2030	4.3130	8.1380	6.9546	5.1400
Anand's Mean	0.7050	0.1350	0.5730	0.2060	4.3910	8.0530	6.9500	5.0620
Pooled Var	0.0192	0.0005	0.0128	0.0010	0.3816	1.2109	0.4064	0.2129
Pooled SD	0.1386	0.0228	0.1129	0.0310	0.6178	1.1004	0.6375	0.4615
Combined Mean	0.6930	0.1370	0.5775	0.2045	4.3520	8.0955	6.9523	5.1010

Table 24: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D01 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Aswin's Mean	0.4600	0.4250	1.1070	0.5740	0.4400	0.5310	0.6781	0.1470
Anand's Mean	0.4460	0.4340	1.1180	0.5640	0.4330	0.5420	0.6660	0.1450
Pooled Var	0.0067	0.0031	0.0083	0.0083	0.0027	0.0038	0.0104	0.0008
Pooled SD	0.0817	0.0557	0.0910	0.0912	0.0524	0.0615	0.1020	0.0283
Combined Mean	0.4530	0.4295	1.1125	0.5690	0.4365	0.5365	0.6720	0.1460

Task	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Aswin's Mean	0.6693	0.1440	0.6040	0.2210	4.6880	9.1160	7.3714	6.0846
Anand's Mean	0.7530	0.1340	0.5930	0.2150	4.7290	9.1320	7.3830	6.0990
Pooled Var	0.0252	0.0055	0.0130	0.0023	0.4191	0.7476	0.4178	0.8541
Pooled SD	0.1588	0.0741	0.1138	0.0475	0.6474	0.8646	0.6464	0.9242
Combined Mean	0.7112	0.1390	0.5985	0.2180	4.7085	9.1240	7.3772	6.0918

Table 25: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D02 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Aswin's Mean	0.4590	0.4127	1.0800	0.5700	0.4100	0.4737	0.6620	0.1520
Anand's Mean	0.4470	0.4230	1.0930	0.5560	0.4040	0.4590	0.6520	0.1530
Pooled Var	0.0048	0.0163	0.0099	0.0109	0.0022	0.0123	0.0083	0.0004
Pooled SD	0.0691	0.1278	0.0992	0.1046	0.0473	0.1107	0.0911	0.0211
Combined Mean	0.4530	0.4178	1.0865	0.5630	0.4070	0.4664	0.6570	0.1525

Task	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Aswin's Mean	0.6990	0.1400	0.5930	0.2170	4.7390	8.4316	7.1590	5.3100
Anand's Mean	0.7080	0.1330	0.5790	0.2120	4.7870	8.5550	7.2830	5.2910
Pooled Var	0.0127	0.0016	0.0127	0.0014	0.5704	0.8006	0.5156	0.1747
Pooled SD	0.1125	0.0397	0.1126	0.0370	0.7553	0.8948	0.7181	0.4179
Combined Mean	0.7035	0.1365	0.5860	0.2145	4.7630	8.4933	7.2210	5.3005

Table 26: Combined Means and Pooled variance elemental tasks in large bolt assembly under Control-D03 condition

Task	Reach Large N-B	grasp N-B	move N-B	Position N-B	Reach Large tool	Grasp Large tools	Move Large tools	Release Large tools
Aswin's Mean	0.4520	0.5530	1.0900	0.5955	0.4170	0.5830	0.6710	0.1490
Anand's Mean	0.4430	0.5440	1.1080	0.5890	0.4060	0.6020	0.6530	0.1480
Pooled Var	0.0064	0.0121	0.0137	0.0127	0.0038	0.0144	0.0163	0.0009
Pooled SD	0.0800	0.1102	0.1170	0.1127	0.0616	0.1200	0.1278	0.0301
Combined Mean	0.4475	0.5485	1.0990	0.5922	0.4115	0.5925	0.6620	0.1485

Task	Reach Large tools	Release Large Tools	Move Large N-B	Release Large N-B	Assemble tool	Assemble hand	Disassemble hand	Disassemble tool
Aswin's Mean	0.6941	0.1330	0.5860	0.2170	6.7680	11.9180	8.7242	6.4580
Anand's Mean	0.7160	0.1380	0.5900	0.2100	6.8980	12.1970	8.8460	6.5510
Pooled Var	0.0316	0.0015	0.0551	0.0021	0.8703	3.5052	0.7936	0.6450
Pooled SD	0.1779	0.0383	0.2347	0.0463	0.9329	1.8722	0.8908	0.8031
Combined Mean	0.7051	0.1355	0.5880	0.2135	6.8330	12.0575	8.7851	6.5045

Table 27: Mean times for the elemental tasks after combining the means (in seconds)

Task	D00	D01	D02	D03
Reach Large N-B	0.4449	0.4530	0.4530	0.4475
grasp N-B	0.3735	0.4295	0.4178	0.5485
move N-B	1.0935	1.1125	1.0865	1.0990
Position N-B	0.5435	0.5690	0.5630	0.5922
Reach Large tool	0.4060	0.4365	0.4070	0.4115
Grasp Large tools	0.2657	0.5365	0.4664	0.5925
Move Large tools	0.6731	0.6720	0.6570	0.6620
Release Large tools	0.1465	0.1460	0.1525	0.1485
Reach Large tools	0.6930	0.7112	0.7035	0.7051
Release Large Tools	0.1370	0.1390	0.1365	0.1355
Move Large N-B	0.5775	0.5985	0.5860	0.5880
Relase Large N-B	0.2045	0.2180	0.2145	0.2135
Assemble tool	4.3520	4.7085	4.7630	6.8330
Assemble hand	8.0955	9.1240	8.4933	12.0575
Disassemble hand	6.9523	7.3772	7.2210	8.7851
Disassemble tool	5.1010	6.0918	5.3005	6.5045

Table 28: Percentage Variation for each scenario over control scenario

Task	D00 vs D01	D00 vs D02	D00 vs D03
Reach Large N-B	1.83	1.83	0.59
grasp N-B	14.99	11.87	46.85
move N-B	1.74	0.64	0.50
Position N-B	4.70	3.60	8.98
Reach Large tool	7.51	0.25	1.35
Grasp Large tools	126.37	96.78	150.00
Move Large tools	0.15	2.39	1.65
Release Large tools	0.34	4.10	1.37
Reach Large tools	2.62	1.52	1.74
Release Large Tools	1.46	0.36	1.09
Move Large N-B	3.64	1.47	1.82
Relase Large N-B	6.60	4.89	4.40
Assemble tool	8.19	9.44	57.01
Assemble hand	12.70	4.91	48.94
Disassemble hand	6.11	3.86	26.36
Disassemble tool	19.42	3.91	27.51

Modifiers D00 Vs D01, D00 Vs D02 and D00 Vs D03 were developed using the combined mean data while the Subramanian's data are from his thesis work (Subramanian A "Developing MTM modifiers for tasks performed by individuals with permanent partial disability of the fingers", 2007 [13])

Table 29: Modifiers Developed for Elemental tasks

Task	D00 Vs D01	Subramanian D00 Vs D01	D00 Vs D02	Subramanian D00 Vs D02	D00 Vs D03	Subramanian D00 Vs D03
Reach Large N-B	1.02	1.01	1.02	1.01	1.01	1.01
grasp N-B	1.15	1.18	1.12	1.15	1.47	1.48
move N-B	1.02	1.01	0.99	1.01	1.01	1.01
Position N-B	1.05	1.03	1.04	1.01	1.09	1.07
Reach Large tool	1.08	1.01	1.00	1.01	1.01	1.01
Grasp Large tools	2.26	2.24	1.97	1.90	2.50	2.48
Move Large tools	1.00	1.01	0.98	1.01	0.98	1.01
Release Large tools	1.00	1.02	1.04	1.02	1.01	1.02
Reach Large tools	1.03	1.03	1.02	1.03	1.02	1.03
Release Large Tools	1.01	1.01	1.00	1.01	0.99	1.01
Move Large N-B	1.04	1.02	1.01	1.02	1.02	1.02
Relase Large N-B	1.07	1.03	1.05	1.03	1.04	1.03
Assemble tool	1.08	1.07	1.09	1.09	1.57	1.57
Assemble hand	1.13	1.13	1.05	1.06	1.49	1.51
Disassemble hand	1.06	1.06	1.04	1.05	1.26	1.27
Disassemble tool	1.19	1.20	1.04	1.05	1.28	1.29

Table 30: Modifiers and the Modified MTM times for Elemental tasks (in seconds)

Task	PMTS Code	PMTS	Modifier D01	Modified time MTM D01	Modifier D02	Modified time MTM D02	Modifier D03	Modified time MTM D03
Reach Large N-B	R12B	0.534	1.018	0.544	1.018	0.544	1.006	0.537
grasp N-B	G1A	0.083	1.150	0.095	1.119	0.093	1.469	0.122
move N-B	M12A	0.534	1.017	0.543	0.994	0.531	1.005	0.537
Position N-B	P1SE	0.232	1.047	0.243	1.036	0.240	1.090	0.253
Reach Large tool	R5B	0.323	1.075	0.347	1.002	0.324	1.014	0.327
Grasp Large tools	G1A	0.083	2.019	0.168	1.755	0.146	2.230	0.185
Move Large tools	M5A	0.302	0.998	0.302	0.976	0.295	0.984	0.297
Release Large tools	RL1	0.083	0.997	0.083	1.041	0.086	1.014	0.084
Reach Large tools	R5B	0.323	1.026	0.331	1.015	0.328	1.017	0.329
Release Large Tools	RL1	0.083	1.015	0.084	0.996	0.083	0.989	0.082
Move Large N-B	M10A	0.468	1.036	0.485	1.015	0.475	1.018	0.477
Relase Large N-B	RL1	0.083	1.066	0.088	1.049	0.087	1.044	0.087

4.3 Assembly – Disassembly Times

Observed times for assembly and disassembly for various scenarios were developed using the combined mean data while the Subramanian's data are from his thesis work (Subramanian A "Developing MTM modifiers for tasks performed by individuals with permanent partial disability of the fingers", 2007 [13])

Table 31: Assembly – Disassembly Times (in seconds)

	Scenario D00		
	Observed time	Subramanian's observed time[13]	MTM time
Assembly	16.444	16.341	16.423
Disassembly	13.716	13.631	13.622

	Scenario D01		
	Observed time	Subramanian's observed time[13]	MTM time
Assembly	18.283	18.192	18.178
Disassembly	15.171	15.178	15.161

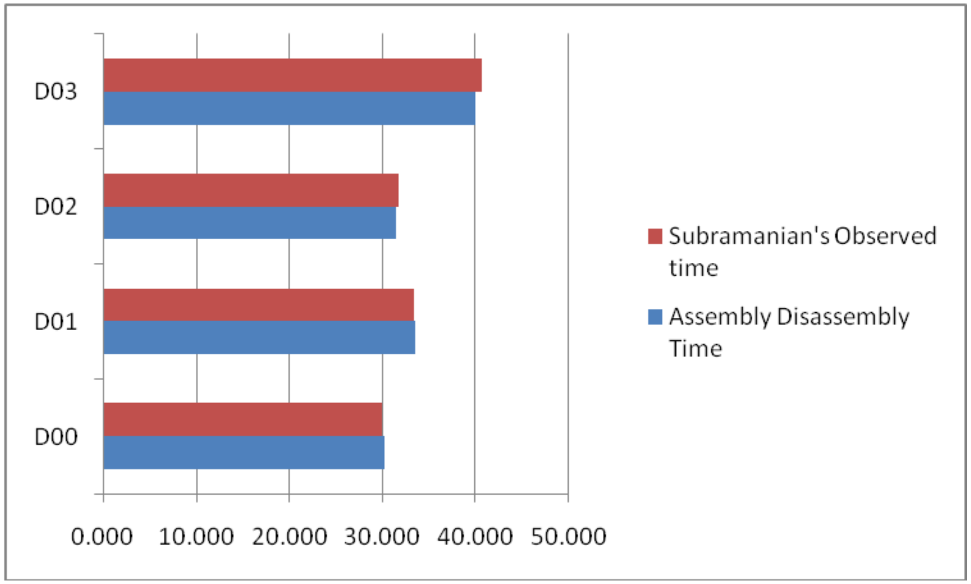
	Scenario D02		
	Observed time	Subramanian's observed time [13]	MTM time
Assembly	17.390	17.529	17.538
Disassembly	14.118	14.208	14.250

	Scenario D03		
	Observed time	Subramanian's observed time [13]	MTM time
Assembly	23.196	23.588	23.534
Disassembly	16.812	17.050	17.050

Table 32: Total Assembly-Disassembly Time Comparison (in seconds)

Scenario	Assembly - Disassembly Time	Subramanian's observed time [13]
D00	30.160	29.972
D01	33.454	33.370
D02	31.508	31.737
D03	40.009	40.638

Figure 18: Comparing assembly-disassembly time



4.4 Results from Typing and Drawing activities

The typing and drawing activities were performed by the volunteers and the results obtained have been tabulated in the following tables.

Table 33: Results from the Typing and Drawing activities

Time in Seconds	D00		D01		D02		D03	
	Reach Keyboard	Type	Reach Keyboard	Type	Reach Keyboard	Type	Reach Keyboard	Type
Mean	0.47	176.25	0.46	219.11	0.47	198.93	0.49	256.03
Median	0.47	160.23	0.47	212.52	0.47	199.22	0.50	247.05
SD	0.06	54.90	0.07	34.64	0.07	52.52	0.06	47.66
Min	0.40	93.90	0.33	170.17	0.33	101.67	0.40	194.77
Max	0.57	315.80	0.57	325.53	0.57	317.17	0.60	371.97
Percentile 5	0.40	113.95	0.37	183.34	0.38	130.17	0.42	195.34
Percentile 10	0.40	124.32	0.40	191.78	0.40	148.22	0.43	205.48
Percentile 25	0.42	148.92	0.40	200.13	0.42	170.67	0.43	226.78
Percentile 50	0.47	160.23	0.47	212.52	0.47	199.22	0.50	247.05
Percentile 90	0.54	240.27	0.56	243.77	0.56	258.12	0.56	310.87

Time in Seconds	D00		D01		D02		D03	
	Reach mouse	Drawing task	Reach mouse	Drawing task	Reach mouse	Drawing task	Reach mouse	Drawing task
Mean	0.46	170.01	0.48	264.70	0.48	166.46	0.48	269.30
Median	0.47	156.92	0.45	272.57	0.48	149.67	0.48	283.40
SD	0.04	39.27	0.08	40.43	0.07	46.65	0.06	59.27
Min	0.40	122.40	0.37	214.43	0.33	125.60	0.40	176.00
Max	0.53	281.50	0.67	334.97	0.57	279.67	0.57	371.03
Percentile 5	0.40	125.03	0.39	216.67	0.38	127.83	0.40	178.10
Percentile 10	0.41	131.93	0.40	218.65	0.40	129.52	0.40	183.72
Percentile 25	0.43	147.53	0.43	225.40	0.44	141.73	0.43	230.40
Percentile 50	0.47	156.92	0.45	272.57	0.48	149.67	0.48	283.40
Percentile 90	0.50	202.13	0.56	312.66	0.57	232.35	0.56	330.55

Table 34: Mean time, Percentage variation and Modifiers for various tasks

Mean Times for all scenarios (in seconds)

	D00	D01	D02	D03
Reach Keyboard	0.467	0.462	0.471	0.487
Type	176.252	219.108	198.925	256.029
Reach mouse	0.464	0.476	0.481	0.479
Mouse handling	170.015	264.704	166.456	269.300

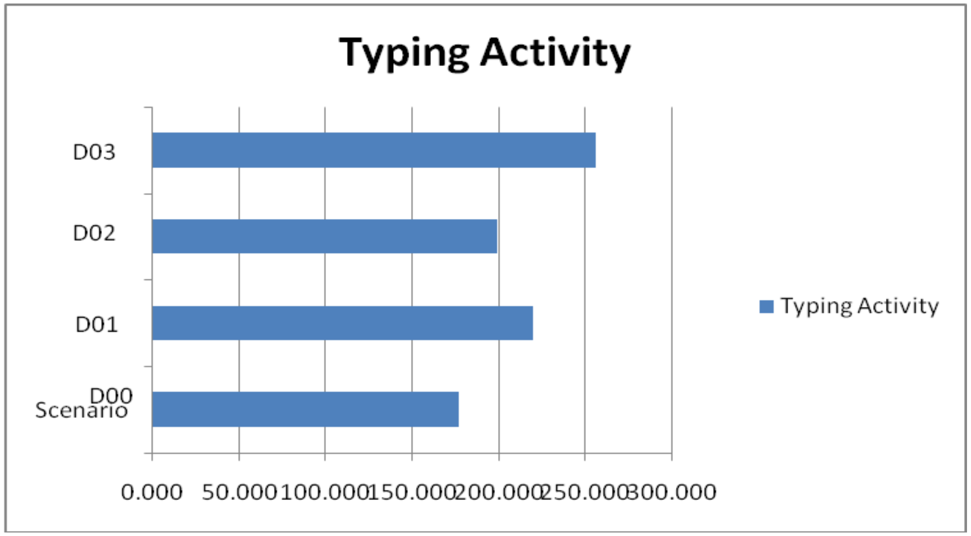
Percentage variation (All values in %)

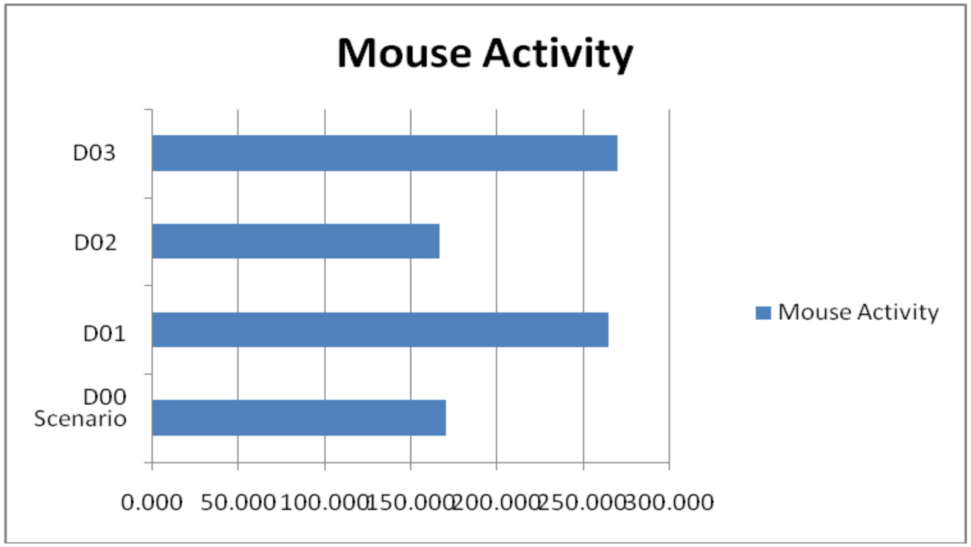
	D01 vs D00	D02 vs D00	D03 vs D00
Reach Keyboard	**-1.099**	**2.124**	**3.370**
Type	24.315	12.864	45.263
Reach mouse	2.605	3.636	3.112
Mouse handling	55.695	-2.093	58.398

Modifiers

	D01 vs D00	D02 vs D00	D03 vs D00
Reach Keyboard	0.989	1.010	1.044
Type	1.243	1.129	1.453
Reach mouse	1.026	1.036	1.031
Mouse handling	1.557	0.979	1.584

Figure 19: Graphs showing the time taken for typing and drawing activity (time in seconds)





5. Discussion

The purpose of this thesis work was to develop modifiers for tasks involved in a large nut-bolt assembly using a set up similar to that of Subramanian so that the results could be compared and the samples could be combined. Also new modifiers were developed for office related tasks such as typing and mouse control related tasks.

After the experiments, the tapes were analyzed and the time taken for each elemental task was calculated. The values were analyzed to find the mean and standard deviation. Then t-tests were performed with Subramanian's values to show that samples are similar. So the means were combined and the variances were pooled so that sample size increases. With these values, the modifiers were developed that are used for the following discussion.

In the assembly activity, time taken for certain tasks did not change despite the disability. Activities such as reach, move and release have modifier values close to 1 indicating the fact that disability has very less impact on the time taken for those tasks. But tasks such as assemble, disassemble, grasp have modifier values much greater than 1. Thus clearly disabilities have a great impact on the time taken for these activities. Increase of time for higher tasks like assemble and disassemble with disability can be attributed to the fact that these disabilities reduce the dexterity. This would lead to a reduction in the person's ability to hold, turn and control the assembly parts such as nut and bolt during the assembly and disassembly activities.

One interesting observation is that for tasks like disassemble using tool and hand, modifier value for scenario D02 is close to 1 while other 2 scenarios have higher modifier value. This would imply that disability to non preferred hand has lesser impact than disability to preferred hand for that task.

For the experiments involving the typing and drawing activities, the reach task had modifiers very similar to the modifiers developed for reach tasks in the large assembly activity. The values were between 1 and 1.02 which is very similar to the range of between 1.01 and 1.02 obtained for the 'reach large nut-bolt' task.

For the experiments involving the typing and drawing activities, another very interesting observation can be made. For the typing activity, the modifiers clearly show that disability increases the time needed to type the text as lesser fingers would decrease typing speed. For the mouse movement activity, scenarios D00 and D02 had very similar times while D01 and D03 had similar timings. This can be attributed to the fact that people use only their preferred had for mouse control and for scenario D02, loss of thumb in non-preferred hand has no effect on mouse control.

For the typing activity, modifiers for D01, D02 and D03 are 1.243, 1.129 and 1.453 respectively. Clearly loss of fingers in the primary hand increased the time taken more than the loss of fingers in the non-preferred hand. Loss of thumb in non-preferred hand resulted in a 12.9% increase in time. Another interesting experiment that can be performed is the study of loss of four fingers in non-preferred hand and to compare that change in time taken to scenario D01 (loss of four fingers in preferred hand).

One of the interesting arguments that can be made would relate to the universal applicability of these modifiers. These modifiers were calculated based on a text that was 100 words long and the drawing was not very complicated and was practiced before the actual experiment. In a real life scenario, typing texts would be longer in nature and the factors such as fatigue would be applicable. Fatigue is induced by the physical and mental demands of the work or due to repeatability. This would affect the efficiency of the working person. Fatigue levels could be affected by disability of fingers as lesser fingers would mean that stress on remaining fingers would be more.

6. Future Research Avenues

Some of the avenues available for future research are

- To create a comprehensive database consisting of modifiers for various disability and task combination. This thesis specifically dealt with finger related disabilities and for tasks related to large nut-bolt assembly, typing and mouse activity. Clearly this is very limited in scope and a wide range of research is needed to cover various disabilities and tasks. Once such a database is created, companies could refer it to plan its work schedule and targets.

- The data collected through such research can be utilized in determining productivity and suitability for employment. Companies can be encouraged to hire disabled people and they can be asked to design wage schemes and work requirements based on the modifiers. For example, we can consider an employee with finger related disability working in an assembly line. The management can apply the modifiers to standard times for all his activities to decide on the target for each day for that person. Such targets would be less than the target set for a person without disability. Such a target would not be a random number but a number based on prior research data and the modifiers.

- Disability studies like this can be used to identify tasks that are most affected by certain type of disability. Once this is done, the next step would be initiate research into modifications or accommodations to facilities that are needed to improve the productivity among disabled people.

- Once accommodations (such as prosthetics) have been developed, new modifiers could be developed to take their effect into account. Thus a database of such results could be created which can be used as a standard for employers to select the best form of accommodation based on the disabled individual's role. This database would also be useful in selecting the best form of accommodation for the disabled employee. For example, a disabled person is assigned to do a particular activity in a large series of activities and that person is expected to perform predominantly just one task (say lifting) effectively. Also consider the case where there are three possible accommodations that could be made for that person to reduce the effects of his injury. In this case company can select the accommodation that would help him perform just the lifting task effectively as that would be his primary task in completing his role in the whole operation.

- Computer based solutions can be developed that take into account the severity of disability to determine the modifiers. For example, we can consider the effects of blindness as a disability. A person could have different degree of blindness and the time taken for that person to complete a task such as typing could vary depending on the severity. Also certain people could be in a position to compensate their disability of one form with extraordinary skills. A person with extremely good designing skills and design software experience might design a machine component faster using a computer despite finger related disability than a person without disability but with limited software and designing skills. So this situation would call for a disability Vs other skills trade-off. Algorithms and Artificial Intelligence programs can be developed to solve such problems.

- Fatigue can set in when a person performs a physically demanding task for a period of time. As fatigue sets in, it results in reduced performance that ultimately affects productivity. The level and rate of fatigue differs from one individual to another. All employees are provided with time allowances to recover from the fatigue. Research could be carried out in the area of effects of disability on the rate and levels of fatigue. For example, if it can be proved that a person performing an assembly task with loss of fingers gets fatigued faster because of more stresses on remaining fingers or other factors, such effects need to be incorporated through additional modifiers.

- The effect of training must be incorporated into the modifiers. It is a proven fact that better training improves efficiency at which work is done. The learning curve is exponential in nature with time taken to produce one unit falling with cumulative production number. According to theory of learning curve, as the quantity of units produced doubles, the time taken per unit declines by some constant percentage [9]. This can be applied to any activity such as typing or drafting. So different individuals would work at different levels despite their disability depending on the training and experience they have had. Such effects need to be studied and their effects need to be incorporated into these modifiers.

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