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DECISION SUPPORT SYSTEM FOR WORKSTATION AND NOTEBOOK COMPUTER SETTINGS FOR ERGONOMIC WORK POSTURE

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A Dissertation Presented

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Abstract

Due to its mobility, light-weight and battery-operated features, notebook computers (NBC)s are getting very popular. Reducing costs and good marketing strategies are promoting people to use NBC more than Desktop Computers (DPC)s. However, a tradeoff from using NBC is the fact that due to its non-ergonomic design, the base-unit connected with the screen-unit with a hinge, prevents it to adjust the screen and the base independent of each other, which results into a bad posture for NBC users. NBC related musculoskeletal disorders (MSD) are increasing but at the same time the trend for NBC usage is increasing too. Various researches have been carried out to recommend good ergonomic posture. A quantitative guideline for NBC usage has not been provided. This research provides two algorithms for recommending notebook computer (NBC) and workstation adjustments so that the user can assume an ergonomic seated posture during NBC operation. Required input data are the user's anthropometric data and physical dimensions of the NBC and the workstation. The first algorithm is based on an assumption that there are no workstation constraints while the second algorithm considers the actual seat height and work surface height. The results from the algorithms include recommendations for adjusting the NBC (tilt angle of the NBC base unit, angle between the base and screen units, and base support height) and the workstation (heights of seat support and footrest, and distance between the body and the NBC). Based on the algorithm a decision support system, *PostureAdjuster* has been developed. *PostureAdjuster* consists of databases, computing algorithms, and user-system interface. Body dimensions, NBC dimensions, NBC angles, NBC-body distance, workstation dimensions, and seat adjustability are the input data needed for computing the work posture. *PostureAdjuster* is able to compute current work posture based on the given data, and recommend ergonomic work postures both with and without workstation constraints. The computed results include body joint angles, viewing distance, incidence angle, NBC – body distance, NBC settings (and support), and workstation settings (and supports). A graphical display of body posture is also shown. The results can be shown on-screen and printed out as hardcopy. RULA Analysis can also be performed using *PostureAdjuster* by manually selecting the inputs from an image. These three features, (i) namely evaluating a current work posture, (ii) recommending ergonomic work posture and (ii) calculating RULA score were validated by testing on 12 subjects and two different workstations. The validation results showed significant improvements in body posture of subjects and reduction of perceived discomfort from subject's opinion, consistent RULA score calculation but the evaluation of a current work posture had some inconsistencies, which could be perfected by further research.

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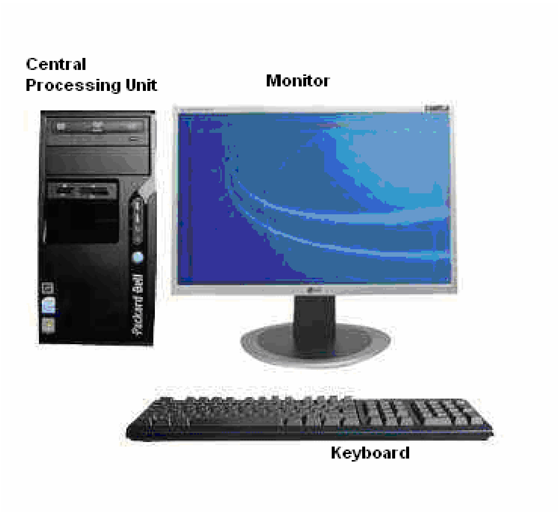
CHAPTER 1

INTRODUCTION

A notebook computer (NBC) is a small mobile personal computer that can be operated with a single battery and an AC/DC adapter which can recharge the battery and also supply power to the NBC at the same time. Typically an NBC weighs between 1 to 8 kilograms depending on the size, material used to make its body and other design factors. An NBC comes with two units, the base unit or the keyboard and the screen unit or the monitor; they are joined together with a hinge. In a desktop personal computer (DPC), the monitor, the central processing unit and the keyboard are all separate units. Figure 1.1 shows the component units of a DPC and NBC. A mouse is considered as an accessory or peripheral device, which can be added with both DPC and NBC. An NBC does come with a track point or touchpad which can be used as a substitute for a mouse.

The initial reason for manufacturing NBCs was to do the tasks that had to be done on the spot and that required short periods of computer input. An NBC cannot be as powerful as a DPC in terms of performance, though technological improvements are enhancing its performance. The benefits of using an NBC is that it is portable, light weight, can be run on battery for 2-3 hours which all adds up to making it very useful for business men, educators, students, managers, salesmen, advertisers, and even scientists on outdoor sites. An NBC is a great tool for presentation. Nowadays, advertisements promote a trend to replace desktop computers with NBCs. Due to its portability, battery operated state of (2-3) hours, affordability and performance, NBCs has become more popular than desktop personal computers. NBC's have become very popular among people of different professions such as businessmen engineers, scientists and especially among teachers and students.



(a) Desktop Personal Computer (DPC)

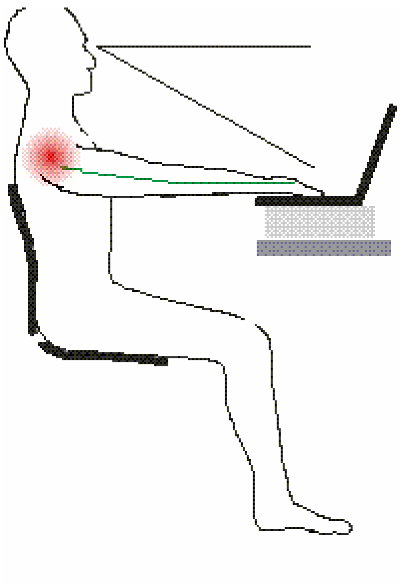
(b) Notebook Computer (NBC)

Figure 1.1 Component Units of DPC and NBC

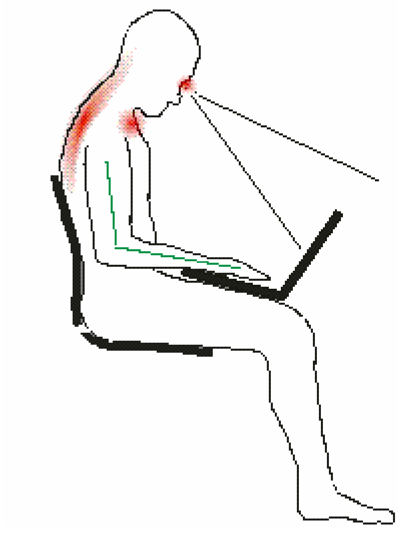
The average cost per notebook decreased from $ 2,126 in the year 2000 to $ 1,116 in the year 2005. Desktops, which have been overshadowed since summer 2005 when notebooks outsold them for the first time, continued to experience a downward trend as momentum for the notebook market picked up. According to news published in the web page of Macintosh News Network (MacNN), the CNET news states the following:

"*Retail notebook sales surpassed desktop sales in 2005 in the United States of America (USA). Notebook sales took up 50.9 percent of the market, while desktops garnered 49.1 percent. The USA only accounts for about nine percent of the market worldwide, and the figures did not include large sales to corporations or direct sales from computer companies. The report says that low prices, higher performance, and the availability of wireless networks are driving notebook sales, which previously were not expected to surpass desktop sales until 2008, the year when NCC sales could overtake desktop sales in USA as predicted by analysts*."

However, there is a drawback of NBC that compromises physical comfort of the users and violates ergonomic principle. If we look back at the computer history we can see that in the second generation of computers, the visual display and the keyboard used to come as one single unit. This resulted in discomfort and musculoskeletal disorders (MSD) that led to injuries among vast number of workers and as a result in the late 1970's a number of ergonomic guidelines were written that stated the screen and the keyboard to be two separate units so that they can be adjusted. The third generation of computers followed this rule. Now as the world has moved to mobile computers or NBCs, it seems that we have been gone a step backwards to the second generation by concocting the screen and the keyboard into one integrated unit in an NBC.



(a) Upper Arm Discomfort



(b) Head-Neck Discomfort

Figure 1.2 Drawbacks of using NBC at (a) Desk Situation and (b) Lap Situation

Due to its hinge design, the base and screen unit of the NBC cannot be adjusted independent of each other. So an ergonomic sitting posture is impossible to obtain for a user when they use the NBC on a desk or on their laps. The comfort of the upper body always has to be compromised while using an NBC. If the screen unit of the NBC is adjusted to the eye-level with the neck in ergonomic posture, then the upper arms have to be extended extensively to reach the keyboard as shown in Figure 1.2 (a). In a lap situation where the arm seems to be comfortable, is worse due to the extensive neck flexion as shown in Figure 1.2(b), which causes extremities around the shoulders and neck region and also causing less blood flow in the head, dizziness etc.

1.1 Problem Statement

The main problem of NBC operation is the lack of a defined workstation for NBC, practice of non-ergonomic posture with NBC and the lack of a quantitative recommendation system. These are described in more detail below.

Unfortunately, campaigners of NBC producers are promoting NBCs in such a way that it can be a personal friend of a user and can be used anywhere anytime. Though this fact is true, but the models used in a typical advertisement often is seen using the NBC in their bed, in the park, or in an airport while waiting for a flight. The postures exposed are non-ergonomic; most of the time they are trying to present the consumers ideas that operating an NBC is fun and one does not need to sit on desk with proper posture. These lead the common users to overlook the non-ergonomic posture and its drawbacks on the body. Moreover, because of its portability a work station is hard to define for a NBC. Typically a workstation for a computer is consisted of a work surface or a table and a seat or a chair. But in reality, we can often see NBC users sitting in very unconventional postures; working in these postures can seriously cause musculoskeletal disorders (MSD). Some of these postures are presented in Figure 1.3.

Figure 1.3 Some common postures adopted by NBC users in unconventional places

NBCs are getting popular globally and this trend will only increase. But with unawareness of its using posture the use of NBCs is a global threat to health of users with prevailing MSD. The main problem of using an NBC is MSDs in the shoulder-neck region and upper arm region. Moreover, there are additional complains from users about dizziness and tiredness of eyes. For these reason there are numerous researches conducted to identify the exact problems or users. Many of them focused on the effect of NBCs and growth of MSDs as a result of using NBCs. Other researches have shown the duration of NBC usage that causes discomfort in the upper body and eyes.

Many researchers have given recommendations of what to do and how to avoid discomforts or minimize the effect. Most ergonomic recommendations consist of '*Do*'s and '*Don't*'s. Though these are very helpful but they cannot provide a complete guideline that can ensure a good posture. Moreover, there are different sizes of NBCs available in the market while the user's body dimensions can vary too. These things have not been taken into consideration yet in many present guidelines. It is noticed that there is a lack of quantitative recommendation that gives complete and precise information of NBC adjustment to reduce MSDs and discomforts of the body. This research is devoted to develop a way to provide quantitative adjustment recommendation of NBC and workstation.

1.2 Objectives

Since there seems to be trouble adjusting a NBC with qualitative guidelines, it is important to develop a system that will help users by providing quantitative recommendations to adjust NBC and workstation in such a way that a good ergonomic posture will be maintained automatically if those adjustments are followed. This system should consider NBC shapes and body dimensions of each individual user so that the recommendations are suited for that particular user. The objectives of this research are:

1. To develop analytical algorithms that provide quantitative results of adjustments of NBC and workstation to maintain a good posture during using an NBC
2. To construct a decision support system that is able to provide :
   - evaluation of a body posture by providing quantitative analysis of body posture which is compared with ergonomic guidelines
   - quantitative recommendations of how to adjust NBC and workstation to obtain good posture during NBC operations

CHAPTER 2

LITERATURE REVIEW

This chapter presents a literature review on musculoskeletal disorders (MSD) and posture of users during computer – DPC or NBC or any kind of visual display terminal (VDT) work. The first section presents MSD – their origin, their effects, substantial researches and results on MSD and other discomforts. The second section focuses on different postures observed during operating DPC or NBC or VDT but mainly focusing on NBC.

2.1 Musculoskeletal Disorders

Musculoskeletal Disorders (MSD) is a condition where a part of musculoskeletal system is injured over some period of time. It refers to a broad range of soft tissue disorders, such as those affecting the spinal discs, muscles, joints, cartilage, nerves, blood vessels, tendons or ligaments. According to Australian Physiotherapy Association, a work related musculoskeletal disorder is any musculoskeletal condition which is caused by work or work practices, including but not limited to repetitive strain injury (RSI), occupational overuse syndrome (OOS), and cumulative trauma disorder (CTD).

Repetitive use of computers especially NBCs under adverse conditions and improper postures can lead up to discomfort, poor concentration, poor performance, fatigue and eventual injuries such as MSD, carpal tunnel syndrome (CPT), lower back pain, stiff shoulders and sore necks. With notebook computers (NBC) users are prone to more severe discomforts due to their use in unconventional places. We know that MSD develop over a time period of work. Initially they are prevalent in the body just as symptoms of body part regions such as discomforts. Hagg's (1991) Cinderella theory explains how static work such as computer work causes pain. The theory states that low-threshold motor units in muscles are activated during a work and stays active until a muscle is totally relaxed; as a result over a longer period with not enough recovery there is metabolic overload in membrane level which causes degenerative process, cell damage, necrosis and pain.

Numerous researches have been conducted to observe the prevalence of MSD among PC users and NBC users. Kadefors and Laubli (2002) presents a chronographic observations of work-related disorders in accounting, administration and communication works, morse machine works, punch card works leading up to computer works in the eighties till the current decade, and all these works can be compared to VDT work due to their similarities in the work procedure. They noticed the increase of MSD among computer users especially around the neck, shoulder region and upper extremity. Bergqvist et al. (1995) found that 20% of regular VDT users had MSD and 60% of regular VDT users had discomfort on the shoulder-neck region. These results show how prone VDT users are towards developing MSD.

The following findings present how fast a discomfort might take place in a user. Straker et al. (1995) reported that with 20 minutes task on a VDT, subjects complained about discomforts; NBC usage caused more discomfort than desktop PC usage and the discomfort occurred in the neck-shoulder region. Horikawa (2001) had done quantitative examination of the relation between screen height and trapezius muscle hardness on subjects using desktop computers and NBCs and the revealed results showed that with 15 minutes of work of data entry on NBC increased hardness of trapezius muscle. Different working habits have different impact and level of discomfort which we can notice from Moffet et al. (2002), who found that while working with NBCs on desk and lap, cause discomforts around neck, shoulder, wrist, upper arm regions. In their study, the lap situation caused more wrist deviation and more neck flexion resulting in more discomfort while the desk situation caused more discomfort in the shoulder and upper arm regions. Using electromyography (EMG) they also observed high levels around the shoulder region during NBC use on a desk and high levels of EMG around neck and wrist during NBC use on the lap. Note that while at rest, EMG of a muscle should be inactive, while high levels indicate high activity of that muscle type.

The discomforts and MSD can occur among the increasing population of NBC users such as children and the consequences can be even worse for their growing body. Straker and Harris (2000) found that among school children 60% of the subjects reported discomfort using NBC regardless of the brand of NBC they used. Their survey also demonstrated that school children with some years experience of NBC usage had more discomfort than school children who had used the NBC less. The places that they had discomfort were neck, shoulder, arms and also eyes and head.

The result of MSD on users can be costly in terms of the cost of medical treatments and number of jobs not performed in time in organizations. A report from the Washington State Department of Labor and Industries states the following information.

"*The magnitude, cost and burden of work-related musculoskeletal disorders (WMSD) are enormous. From 1992–2000, there were 380,485 Washington state accepted workers' compensation state fund claims for nontraumatic soft tissue musculoskeletal disorders of the neck, back and upper extremity. These claims resulted in $2.9 billion in direct costs, and 26.9 percent of all state fund workers' compensation claims. Of WMSD claims during this time period, 32.4 percent were compensable with an average of 123 lost time days per compensable claim.*"

2.2 Body Posture during Computer Work

Body posture during DPC or NBC use depends on the workstation settings of a PC or NBC. In case of a DPC it is easy to adjust the monitor and the keyboard and other peripheral devices independently of each other. In case of NBC the screen and the base unit cannot be adjusted independently, since they are connected with a hinge thus resulting in a constrained posture of the body. Body posture regarding DPC or NBC use is presented here.

Straker et al. (1997)a have shown a comparison of postures during desktop PCs and NBCs. Significant postural differences in neck angles and head tilt angles were found while using DPCs and NBCs. The trend for a greater neck flexion was noticed during NBC use. These differences were noticed irrespective of the subjects' previous knowledge or experience with each type of computers. Their test results have also shown that compromised body posture for notebook computer where the compromise mainly occurred around the neck area. Szeto and Raymond (2002) showed that due to lower screen heights there is increased muscle flexion around cervical and thoracic spines on subjects while using NBCs. The forward neck flexion posture also increased the load on the spine resulting the participants to adjust their posture more in the cervical spine while using the thoracic spine to stabilize the body. In addition the subjects also had eye and vision discomfort for prolonged use of NBCs and its types, since the viewing distances were lesser than recommended viewing distances for any VDT.

The findings of both Straker et al. (1997)a and Szeto and Raymond (2002) are very consistent with Villanueva et al. (1996). They tested with 5 different VDT heights on 10 subjects and concluded that neck angle is significantly related with a VDT height and a higher neck flexion is caused by lower VDT height. Results and conclusions of Moffet et al. (2000) also are in agreement with the postures of the others. In their results, the placement of a laptop's keyboard and screen in the vertical position influences the posture adopted by its users. In a lower placement of keyboard and the screen, more forward neck bending, trunk inclination and wrist extension occurs. While with a higher placement the upper arm elevation is increased while the neck bending is decreased. In a test of using a NBC on desk and lap situations, they observed more stress on the shoulder/upper arm region for the desk situation and more stress on the neck region for the lap situation. Straker et al. (1997)b, presented the effect of shoulder posture on work performance, discomfort and fatigue with comparisons of 0º and 30º of shoulder flexion. Test results indicated that fatigue around anterior deltoid was significantly affected by the 30º posture.

An NBC consists of a base-unit or keyboard and screen-unit or the monitor and there is a touchpad to control the mouse pointer. Touchpad is an important factor in a NBC. To investigate the influence of a touchpad's location in a NBC, Sommerich et al. (2001) conducted research and concluded that touchpad location significantly affected NBC user's posture, biomechanics and discomfort. The touchpad locations also affected neck/shoulder discomfort. They recommended a touchpad location on the right side or on the left-side (for left-handers) and suggested touchpad as a peripheral device. It can be observed in real life that for convenience, people use external mouse with their NBC for better performance and comfort. This supports the conclusions reported by Sommerich et al. (2001).

Since the NBC base and screen units cannot be adjusted independent of each other, which forces the users to have a constrained posture, it is a good idea to use an external keyboard so that it can be placed in the arm height and the monitor of the NBC could be adjusted to proper eye-level height. Sommerich et al. (2002) conducted a detailed study of evaluating effects of notebook computers in stand-alone condition and with inexpensive ordinary peripheral input devices, such as external keyboard, mouse and numeric pads. They checked the effects on the head and neck angles, trunk angle and thoracic bend, shoulder and elbow angles, wrist posture. From their results on posture and discomforts, it was noticeable that during using a stand-alone notebook computer, the postures were more deviated from neutral positions of the body. From the results of this study, it can be concluded from their tests that use of external devices such as keyboard can reduce neck flexion and thus the stress on the neck.

As reviewed in this chapter we can see many researches about discomfort levels of user's body during PC and NBC or any VDT operation. Also there have been researches about posture of body, posture tradeoffs during using different height level or VDT. However, there is a lack of a complete analytical guideline to adjust NBC in reference to the body. In case of VDT, Rurkhamet and Nanthavanij (2004)a have developed analytical design methodology which consists of body reference points of subjects' reference points of computers. They also provide with practical algorithms to adjust desktop computer and accessories in order to sit in correct posture. This design fills up the lack of desk evaluation for paper and computer-based work as mentioned by Straker et al. (2006), with analytic approach of using the same desk for both computer and paper-based work. Consequently, Rurkhamet and Nanthavanij (2004)b have developed a rule-based decision support system EQ-Dex based on the previous algorithm. EQ-Dex is user interactive and provides numerical values and line figures to illustrate the recommendations of desktop computer and accessories layout. This research adopts a similar analytical approach for adjustment of the NBC.

CHAPTER 3

ERGONOMIC GUIDELINES FOR PROLONGED COMPUTER WORK

Computer related injuries are occurring with the explosion of computer technology in daily life. Prolonged and repetitive work with computers whether it is desktop or a notebook, can create discomfort, muscle aches, and be the cause of other musculoskeletal disorders. So an ergonomic guideline is essential to follow in order to be safe from work related injuries with computer.

3.1 Working with Desktop Personal Computer (DPC)

There are many guidelines of using a DPC provided by OSHA (Occupational Safety and Health Administration) of USA, OSHA Canada, OSH (Occupational Safety and Health) Australia, OSH New Zealand, Human Factors Ergonomics Society (HFES) to name a few. Some links are listed below:

- http://ehs.ucdavis.edu/ftpd/ergo/ComputerErgo.pdf
- http://www.oshcanada.com/oshanswers/ergonomics/office/risk_factors.html
- http://www.ccohs.ca/oshanswers/ergonomics/office/
- http://www.ascc.gov.au/NR/rdonlyres/AF07B7B1-5B90-4868-8E60-29AF0CC2FB41/0/ErgonomicPrinciplesOfficeFurniture.pdf
- http://www.mcs.vuw.ac.nz/comp/General/OOS/howtosit.gif
- http://www.osh.govt.nz/order/catalogue/pdf/howtousevdu.pdf

All their guidelines are available in their web pages. The guidelines come in terms of placement of the keyboard, the monitor and the mouse and also use of right furniture etc. Below the gist information is provided to adjust the keyboard, monitor and a mouse of a DPC.

3.1.1 Keyboard

It is recommended that the keyboard be at the arm level letting the arms resting on the keyboard in such a way that the upper arm and the lower arm form a 90˚ angle. The keyboard should be in a position that allows the forearms to be close to the horizontal and the wrists to be straight. That is, with the hand in line with the forearm and the elbow closed to the body. The wrist should not be extended or bent.

3.1.2 Monitor

It is recommended that the eye-to-screen distance should be set at the distance that permits the user to most easily focus on the screen. The height of the monitor should be set such that the top of the screen is below eye level and the bottom of the screen can be read without a marked inclination of the head and the centre of the screen will need to be near shoulder height.

3.1.3 Mouse

When a mouse is used while keying, it is important that it is accessed without overreaching or using awkward postures. To accomplish the mouse has to be placed as close to the keyboard as possible. It is also recommended not to use an oversized or undersized mouse.

3.1.4 Body Posture

According to ANSI/HFS 100-1988 Standard the following guidelines should be maintained for a VDT user

1. User should sit with the back at an upright (or slightly reclined) position,
2. Upper arms should hang naturally along the side of the trunk,
3. Elbows are fixed at 90° while keeping the lower arms horizontal,
4. Lower arms and hands should form a straight line,
5. Lower legs should form a right angle (90°) with the upper legs,
6. Both feet should rest comfortably on the floor, and
7. Monitor should be placed such that the user can view the screen comfortably without bending his/her neck.

Figure 3.1 illustrates an ergonomic posture with a DPC. Since the keyboard and monitor of modern day's desktop computers come as separate units, it is possible to adjust the partially or fully adjustable VDT workstation so that the above described posture can be obtained. A computerized tool such as EQ-DeX can be used to provide practical recommendations for adjusting the VDT workstation and arranging computer accessories on the work surface area (Rurkhamet and Nanthavanij, 2004b).

Figure 3.1 An Ergonomic Seated Posture with a DPC

3.2 Working with Notebook Computers

In case of an NBC the base and screen units are connected by hinges, so that it can be portable. But this design prohibits the heights of the base (or keyboard) and screen (or monitor) from being adjusted independent of each other. So this condition imposes restriction on the body posture. If the screen is positioned such that the user's neck is in an ergonomic posture, the forearms must be raised to reach the keyboard, causing both wrists to flex excessively. On the other hand, if the keyboard is ergonomically positioned at the height of forearms, the wrists will be fine but the neck must be flexed to view the screen. The fact that notebook computers can be used at places such as classroom, library, coffee shop, airport, cafeteria, to name a few, also makes it difficult to define exactly what the NBC workstation is.

This section, some recommendations related to the work posture during NBC operation are described.

3.2.1 Neck

Lueder (1996) revised the RULA technique so that it can be used to assess work posture during VDT operation. Based on the revised RULA, a minimum score (indicating low risk) for neck posture is given when neck flexion does not exceed 10°. Harris and Straker (2000) also mentioned that neck flexion of more than 15° causes fatigue when operating VDTs. According to Straker et al. (1997a), at neck angles of 11°-16°, the load on the neck is 280 N and it increases as the neck angle is increased. Readers should note that neck flexion is inevitable in order to view the screen so that the incidence angle of the line of sight is perpendicular to the screen surface.

3.2.2 Shoulder

Straker et al. (1997b) showed comparisons between a shoulder angle of 0° and 30° over a 20-minute work period and concluded that a shoulder flexion of 0° is preferable to that of 30° since subjects reported six times less discomfort. As for the RULA, the minimum score for upper arm posture is given when shoulder flexion is kept below 20°.

3.2.3 Viewing Distance

Based on four workstation design factors, namely, keyboard height, screen height, workstation illumination, and glare, Stammerjohn et al. (1981) recommended that an acceptable range of the viewing distance for VDT operation be between 45 and 70 cm. Saito et al. (1997) conducted an evaluation of working conditions and musculoskeletal posture on ten subjects by comparing viewing distance, viewing angle, head angle, neck angle, and electromyography (EMG) on neck, back, and shoulder muscles. For the viewing distance, they reported that NBC operation resulted in the viewing distance that is 8 cm less than the distance for desktop computer operation. Later, Moffet et al. (2002) evaluated working postures while operating NBCs and confirmed the findings reported in Saito et al. (1997). For simplicity, it can be concluded that the viewing distance for NBC operation should range between 38 and 62 cm.

3.2.4 Guidelines for NBC usage

From the general recommendations given in the ANSI/HFS 100-1988 Standard and the above recommendations, the following rules can be concluded:

1. The NBC user should sit with the back at an upright (or slightly reclined) position; neck flexion should not be more than 10°.
2. The shoulder flexion of the user should not be more than 20°
3. The elbow flexion should be close to 90°
4. The lower arms and hands should form a straight line thus imposing no flexion around wrist.
5. The lower legs should form the right angle (90°) with the upper legs; both feet should rest comfortably on the floor.
6. The viewing distance should be between 38 and 62 cm.

Figure 3.2 shows an ergonomic posture during NBC usage that follows the above six rules.

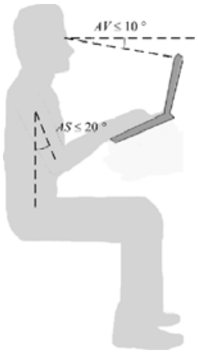


Figure 3.2 Ergonomic Posture for NBC following the six Rules

CHAPTER 4

ANALYTICAL ALGORITHMS FOR NOTEBOOK COMPUTERS AND WORKSTATION ADJUSTMENT

This chapter provides two algorithms for recommending notebook computer (NBC) and workstation adjustments so that the user can assume an ergonomic seated posture during NBC operation. The algorithms are able to make recommendations for each individual user and the particular NBC they use. There are two algorithms namely, the algorithm without workstation constraints and the algorithm with workstation constraints. The first algorithm gives recommendation of body and NBC adjustments by providing workstation height. The second algorithm is used in case the user already has some existing workstation; the algorithm gives recommendations for body and NBC adjustment and additionally workstation adjustment to modify user's current workstation by adding seat support, base support and foot rest, if they are required.

The algorithms take into account the side view of the body, NBC and workstation on the *xy*- plane. They utilize reference points of body and notebook computer, some essential dimensions of body, notebook computer and workstation, several formulas to compute angles and dimensions and finally the analytic steps. This chapter presents the above mentioned items first thus leading up finally to the two algorithms that have been developed.

4.1 Required Dimensions

Both algorithms require some dimensions of the body, the notebook computer and the workstation. Without these dimensions the accurate recommendations for body and NBC adjustment cannot be provided. Below each type is defined.

4.1.1 Body Part Dimensions

The human body in an ergonomic seated posture has been divided into different segments based on anthropometry. The following anthropometric data have been chosen to represent a computer user's body in a seated posture. They are:

(1) Eye height (seated) *IH*,
(2) Shoulder height (seated) *SH*,
(3) Length of upper arm *UA*,
(4) length of lower arm *LA*,
(5) Length of hand *HA*,
(6) Popliteal height (seated) *HH*,
(7) Length of upper leg *UL*, and
(8) Length of lower leg *LL*.

In addition, the body height *BH* is also required. Figure 4.1 illustrates these dimensions. All dimensions are measured in centimeters (cm).

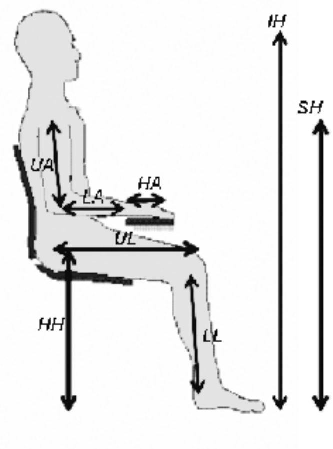


Figure 4.1 Required Body Dimensions

Currently all the body dimensions collected are from the anthropometric data of Thai population (Thai Industrial Standards Institute, 2001). Each body dimension is expressed as a proportion of the body height *BH*. This is done in order to develop body dimension estimation formulas- formulas that can determine the length of all body segments by knowing only *BH*.. Table 4.1 shows selected anthropometric data expressed as average proportions of body height for the 5th, 50th, and 95th percentiles for both male and female population. The 5th, 50th and 95th percentiles are denoted as P5, P50 and P95, respectively.

Table 4.1 Selected Anthropometric Data of Thai population
(as proportions of Body Height, *BH*)

	Male			Female		
	P5	P50	P95	P5	P50	P95
Body height (*BH*, cm)	157.9	166.8	177.1	146.4	155.0	163.5
Eye height (sitting) (*IH*)	0.7054	0.7219	0.7336	0.6971	0.7115	0.7262
Shoulder height (sitting) (*SH*)	0.5798	0.6134	0.6429	0.5880	0.6026	0.6193
Length of upper arm (*UA*)	0.2027	0.2085	0.2122	0.2049	0.2105	0.2154
Length of lower arm (*LA*)	0.1600	0.1668	0.1731	0.1503	0.1548	0.1590
Length of hand (*HA*)	0.1140	0.1169	0.1193	0.1134	0.1161	0.1183
Popliteal height (sitting) (*HH*)	0.2604	0.2685	0.2754	0.2426	0.2518	0.2604
Length of upper leg (*UL*)	0.3305	0.3393	0.3463	0.3459	0.3518	0.3590
Length of lower leg (*LL*)	0.2981	0.3054	0.3125	0.3160	0.3215	0.3261

From Table 4.1, it is seen that there are six sets of formulas to estimate the required anthropometric data from the user's body height. The following rules are used to determine which formula set will be used when the body height is given.

Male:

$BH \leq 162.4$ - use the formula set for P5

$162.4 < BH \leq 172.0$ - use the formula set for P50

BH > 172.0 - use the formula set for P95

Female:
BH ≤ 150.7 - use the formula set for P5
150.7 < BH ≤ 159.3 - use the formula set for P50
BH > 159.3 - use the formula set for P95

Note that the ranges are determined as mid-points between the body heights from two adjacent percentile values. For example, for the formula set for P5-male, the upper bound body height of 162.4 cm is a mid-point between 157.9 cm and 166.8 cm. It is assumed that when NBC users operate the keyboard, their fingers are normally flexed instead of being fully extended. Thus, the distance between wrist joint and fingertip is assumed to be 75% of the hand length *HA*.

4.1.2 Notebook Computer Dimensions

Viewing an NBC from the side, the following dimensions, all measured in centimeters (cm), are required by both algorithms :

(1) Length from front edge to home row (row-length) *RL*,
(2) Length from front edge to rear edge (base-length) *BL*, and
(3) Length from top edge to bottom edge (screen-length) *SL*

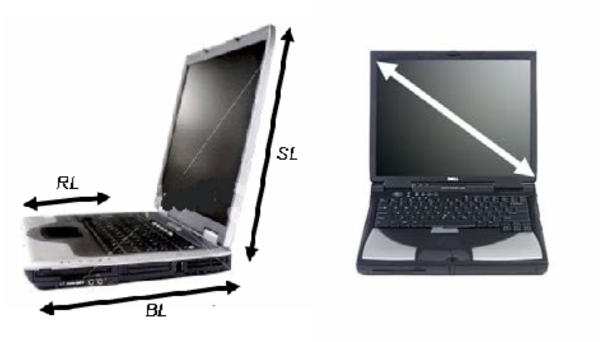


Figure 4.2 Required NBC Dimensions (left), the Screen-size (right)

In addition the screen size of the NBC is also required by the algorithms. Figure 4.2 shows the required dimensions of an NBC. The screen-size is required to create formulas to average the *RL*, *BL* and *SL* from knowing the screen-size of an NBC. The purpose behind this average technique is that, an NBC come in various sizes; the size of NBC is typically defined by its screen size. (Conventionally, the NBC screen is measured diagonally and expressed in inches.) It is also noted that the screen and base units of the NBC are of the same dimensions, both length and width. Therefore, the NBC that has a small screen tends to have a small keyboard area. Five NBC sizes that are very popular among NBC users are:

(1) 11.1-inch NBC
(2) 12.1-inch NBC
(3) 13.3-inch NBC
(4) 14-inch NBC and 14.1-inch NBC
(5) 15-inch NBC and 15.4-inch NBC

Table 4.2 Average Dimensions of Selected NBC Parts

NBC Part	NBC Size[a]				
	11.1-inch	12.1-inch	13.3-inch	14-inch[b]	15-inch[c]
Front edge – home row (base)	9.80	12.35	13.53	13.71	15.22
Front edge – rear edge (base)	17.90	20.85	22.31	23.63	26.35
Top edge – bottom edge (screen)	18.10	20.78	22.77	23.55	26.35

[a]Diagonal measure of NBC screen
[b]Average dimensions of 14-inch and 14.1-inch NBCs
[c]Average dimensions of 15-inch and 15.4-inch NBCs

Table 4.2 shows the average dimensions of these three NBC dimensions for different NBC sizes.

4.1.3 Workstation Dimensions

A workstation consists of a work surface or table and a seat or a chair. Dimensions required by the algorithm from the workstation are shown in figure 4.3, which are:

(1) Height of the work surface or table (*AWH*)

(2) Height of seat or chair (*AHH*)

The algorithm considers a seat or chair to be of two types namely, adjustable and non-adjustable. In case of an adjustable seat the required dimensions are the minimum and maximum heights of the seat.

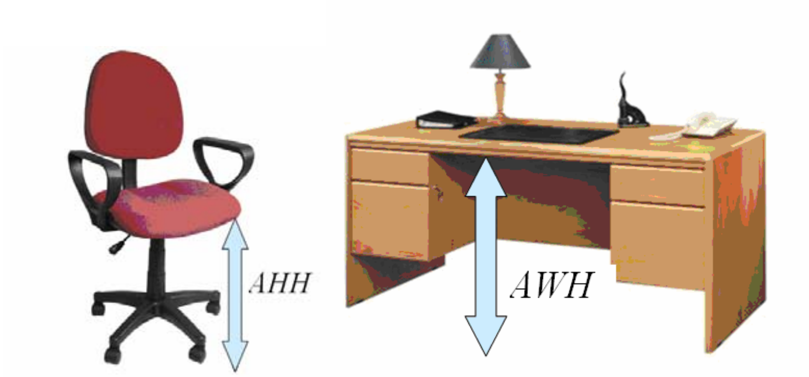


Figure 4.3 Required Workstation Dimensions

4.2 Reference Points

Having known the required dimensions of the body, NBC and workstation (required only for the second algorithm), the algorithms need to locate or fit the body in a side view or *xy*-plane. Reference points have been chosen to plot the body, NBC on that plane. Below these reference points are described separately.

4.2.1 Body Reference Points

Considering the side view of the human body on a sagittal plane several points of the body are used as reference points. They are:

(1) Eye *I*,
(2) Shoulder joint *S*,
(3) Elbow joint *E*,
(4) Wrist joint *W*,
(5) Fingertip at the middle finger *M*,
(6) Hip joint *H*,
(7) Knee joint *K*, and
(8) Ankle joint *A*.

The letter in braces followed by each reference point is used to represent them. Figure 4.4 shows the body reference points. These reference points are in fact the end points of each of the required body dimensions mentioned in section 4.1.1. In other words two reference points can be joined to find a body dimension, for instance, the distance between shoulder joint *S* and elbow joint *E* is the body dimension *UA*.

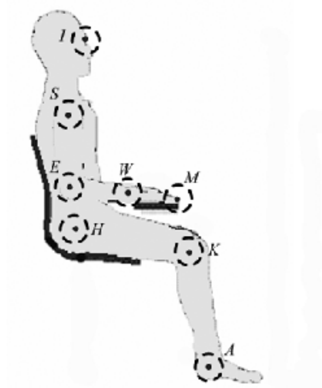


Figure 4.4 Body Reference Points

4.2.2 NBC Reference Points

On the same *xy*-plane, selected reference points of NBC are defined as follows:

(1) Keyboard's home row *R*,
(2) Front edge of the base unit *F*,
(3) Rear edge of the base unit *B*,
(4) Bottom edge of the screen unit *B*, and
(5) Top edge of the screen unit *T*.

Figure 4.5 shows these NBC reference. Note that the rear edge of the base unit and the bottom edge of the screen unit are the same reference point. These reference points of NBC are in fact the end points of each of the required body dimensions mentioned in section 4.1.2. In other words two reference points can be joined to find a dimension of NBC, for instance, the distance between front edge *F* and keyboard's home row *R* is the NBC dimension *RL*.

Figure 4.5 NBC Reference Points

4.3 Formulas for Computation

In every step of the adjustment algorithms, there are lengths, distances, angles, and intersection points that need to be calculated. The calculations take place in each step of the algorithm and based on the results, the body and NBC are plotted on the *xy*- plane in each step. Various formulas are used. There are three core formulas that are used for calculating distance between points, angles and intersection points. Moreover, there are formulas for locating coordinates of body reference points and NBC reference points.

4.3.1 Formulas for Distance, Angle, Intersection Point measurement

These are the formulas from Euclidean Geometry of coordinates. They are:

1. Distance or length measuring formula: When points P and Q are given, a straight-line distance PQ between them can be determined from

$$PQ = \sqrt{\left(P_x - Q_x\right)^2 + \left(P_y - Q_y\right)^2}$$

The viewing distance VD, defined as the distance between the reference points I and T is measured using this formula. Besides, at several steps in the algorithm, this formula is used to check some length for the purpose of double checking certain lengths of body or NBC.

2. Angle measuring formula: When points P, Q, and R are given and lines PQ and QR are drawn, an angle α between PQ and QR can be determined from

$$\alpha = \cos^{-1}\left[\frac{(P_x - Q_x)(R_x - Q_x) + (P_y - Q_y)(R_y - Q_y)}{PQ \times QR}\right]$$

All angles are computed using this formula.

3. Intersection point locating formula: For two overlapping circles A and B (with radii r_A and r_B, respectively) whose centers are at points C and D, respectively, their intersection points E and F could be found from

$$E_x = \frac{D_x - C_x}{2} + \frac{\left(D_x - C_x\right)\left(r_A^2 - r_B^2\right)}{2d^2} + \frac{D_y - C_y}{2d^2}\sqrt{\left[\left(r_A + r_B\right)^2 - d^2\right]\left[d^2 - \left(r_B - r_A\right)^2\right]}$$

$$E_y = \frac{D_y - C_y}{2} + \frac{\left(D_y - C_y\right)\left(r_A^2 - r_B^2\right)}{2d^2} - \frac{D_x - C_x}{2d^2}\sqrt{\left[\left(r_A + r_B\right)^2 - d^2\right]\left[d^2 - \left(r_B - r_A\right)^2\right]}$$

$$F_x = \frac{D_x - C_x}{2} + \frac{\left(D_x - C_x\right)\left(r_A^2 - r_B^2\right)}{2d^2} - \frac{D_y - C_y}{2d^2}\sqrt{\left[\left(r_A + r_B\right)^2 - d^2\right]\left[d^2 - \left(r_B - r_A\right)^2\right]}$$

$$F_y = \frac{D_y - C_y}{2} + \frac{(D_y - C_y)(r_A^2 - r_B^2)}{2d^2} + \frac{D_x - C_x}{2d^2}\sqrt{\left[(r_A + r_B)^2 - d^2\right]\left[d^2 - (r_B - r_A)^2\right]}$$

where $d = \sqrt{(D_x - C_x)^2 + (D_y - C_y)^2}$

This formula is used in certain adjustment steps to locate the elbow joint *E*, when the NBC has been placed and adjusted in such a way that it is assuring our intended neck posture but the arms are yet to be placed.

4.3.2 Formulas for Body Reference Points and Angles

By mapping the body on the sagittal (*x*, *y*) plane, we can determine the (*x*, *y*) coordinates of the body reference points. These angles are required by the algorithms and measured using the second formula for section 4.3.1.

These angles are defined as,

- *AE* = elbow angle, measured between the upper and lower arms,
- *AS* = shoulder flexion angle, measured between the trunk and upper arm, and
- *AV* = viewing angle, measured between the horizontal line and the normal line of sight (at the screen top)

Assuming that the reference vertical line is the line that passes the mid points of the head and trunk, we obtain the coordinates of all body reference points using the following formulas.

Eye (*I*):	I_x =	5
	I_y =	*IH*
Shoulder joint (*S*):	S_x =	0
	S_y =	*SH*
Elbow joint (*E*):	E_x =	$S_x + (UA \times \sin AS)$
	E_y =	$S_y - (UA \times \cos AS)$
Wrist joint (*W*):	W_x =	$E_x + (LA \times \cos\|AE - 90°\|)$
	W_y =	$E_y + (LA \times \sin\|AE - 90°\|)$
Fingertip (*M*):	M_x =	$E_x + [\{(0.75 \times HA) + LA\} \times \cos\|AE - 90°\|]$
	M_y =	$E_y + [\{(0.75 \times HA) + LA\} \times \sin\|AE - 90°\|]$
Ankle joint (*A*):	A_x =	*UL*
	A_y =	0
Knee joint (*K*):	K_x =	A_x
	K_y =	$A_y + LL$
Hip Joint (*H*):	H_x =	0
	H_y =	K_y

4.3.3 Formulas for NBC Reference Points and Angles

By mapping the NBC on the same sagittal (*x*, *y*) plane, we can determine the (*x*, *y*) coordinates of the NBC reference points. These angles are required by the algorithms and measured using the second formula for section 4.3.1.

- *AB* = tilt angle of NBC base unit
- *BS* = screen angle, measured between the NBC base and screen units
- *ES* = incidence angle, measured between the normal line of sight and the screen surface

The coordinates of the NBC reference points can be calculated with the following formulas. After the body has been plotted on the *xy*-plane the NBC is plotted starting with the location of the Home row *(R)*, where Home row (*R*) and Fingertip (*M*) is assumed to be the same point because the user has to place the fingers on the home row for typing.

Home row (R): $R_x = M_x$

$R_y = M_y$

Front edge (F): $F_x = R_x - (RL \times \cos AB)$

$F_y = R_y - (RL \times \sin AB)$

Rear edge (B): $B_x = F_x + (BL \times \cos AB)$

$B_y = F_y + (BL \times \sin AB)$

Top edge (T): $T_x = B_x + \{SL \times \sin(BS - 90°)\}$

$T_y = B_y + \{SL \times \cos(BS - 90°)\}$

Note, that angle *ES* is not used by any formulas; it is used in the analytical algorithm described in section 4.4.

4.4 Adjustment Algorithms

There are two adjustment algorithms. In the first algorithm, it is assumed that there are no workstation constraints. That is, the algorithm freely positions the body and the NBC to form the seated posture described in Chapter 3, and provides the coordinates of all reference points as the outputs. This algorithm helps to determine the adjustment recommendations to obtain the best possible ergonomic seated posture when working with the NBC.

In reality, most NBC users normally sit on a chair and place their NBC on a table during their NBC operation. This imposes two workstation constraints, namely, seat and work surface heights. These constraints are necessary to simulate the real work situation of NBC users. More specifically, they are pre-requisites for realistic adjustment recommendations. The second algorithm considers both workstation constraints and imports the adjustment recommendations from the first algorithm, conceptually positions the body and the NBC at the given workstation, and recommends the heights of footrest, seat support, and NBC base support wherever necessary.

4.4.1 Algorithm without Workstation Constraints

The algorithm without workstation constraints, functions in three stages. It follows all the guidelines provided in Section 3.2.4 and uses them as constraints that need to be satisfied during adjustments.

Stage 1: Initially it considers the user's body seated in an ergonomic posture as figure 3.1. At this posture all reference points of body and NBC, all angles regarding body and NBC are determined using the formulas of section 4.3.

Stage 2: The algorithm's first priority is to keep the body in this ergonomic posture. In order to have a clear view of the screen the incidence angle *ES* should be 90º. If in this position *ES* is not 90º, *ES* is adjusted by adjusting (reducing or increasing) the screen angle *BS*. Once the *ES* value of 90º is obtained, conditions regarding the viewing angle *AV* and viewing distance *VD* are checked. If all conditions hold, a perfect ergonomic posture for using NBC is obtained, otherwise the algorithm moves on to a new approach of adjustment in the next stage. Note, that practically it is impossible to obtain a posture from this stage. Figure 4.6 illustrates the adjustments in this stage.

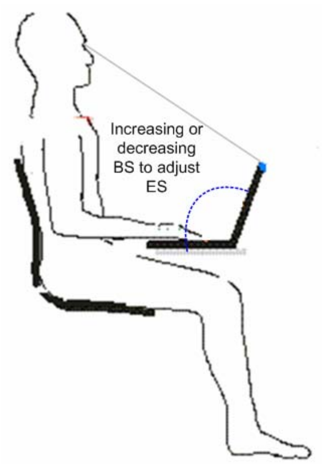


Figure 4.6 Adjustments in Stage 2

Stage 3: At this stage, the algorithm takes a different approach of adjustment. The conditions for viewing angle *AV* and incidence angle *ES* are met first keeping them at 10º and 90º respectively while the viewing distance *VD* is set to the maximum allowable range of 62 cm. Now the base-unit is adjusted by making adjustments in *BS* and the fingertip (M), wrist (W) and elbow (E) are relocated on the new position on the base-unit. After the relocation procedure, if the shoulder angle is not more than 20º then the posture is accepted and coordinates of all reference points of the body and NBC are found and necessary quantitative recommendations are presented for the user to obtain that posture. Otherwise, the viewing distance *VD* is decreased by 1 cm and the all steps of stage 3 are repeated until the posture is found. Every time *VD* is decreased, the algorithm also checks that it does not decrease below 38 cm. With real anthropometric data it was seen that a case of *VD* going below 38 cm never occurs. Figure 4.7 gives a picture of adjustments in Stage 3.

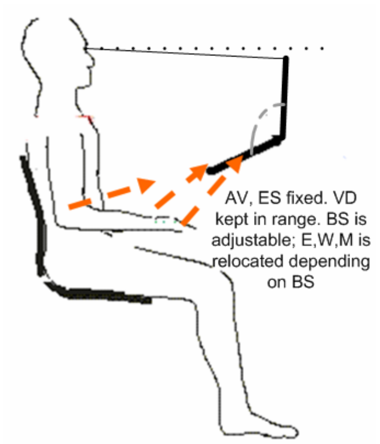


Figure 4.7 Adjustments in Stage 3

The functions of the above three stages are executed in the following 16 steps. Figure 4.8 presents a flowchart of this algorithm.

Initialization:

$AS = AW = 0°$

$AE = 90°$

$BS = 120°$

The NBC base unit is positioned on the same axis as the lower arm – hand axis (i.e., $AB = 90° + AS - AE$)

Adjustment Procedure:

Step1. Given *BH*, determine *IH*, *SH*, *UA*, *LA*, *HA*, *HH*, *UL*, and *LL*.

Step2. Determine I_x, I_y, S_x, S_y, H_x, H_y, K_x, K_y, A_x, A_y, E_x, E_y, W_x, W_y, M_x, and M_y.

Step3. Determine R_x, R_y, F_x, F_y, B_x, B_y, T_x, and T_y.

Step4. Determine *ES*.

Step5. Check if $ES = 90°$:

- If $ES = 90°$, proceed to Step6.
- If $ES < 90°$, decrease *BS* by 1°. Then, check the new *BS*.
  - -If $BS > 90°$, determine T_x, T_y, and *ES*. Repeat Step5.
  - -If $BS = 90°$, determine T_x, T_y, and *ES*. If $ES = 90°$, proceed to Step6.

  Otherwise, stop (infeasible posture).
- If $ES > 90°$, increase *BS* by 1°.
  - -If $BS < 180°$, determine T_x, T_y, and *ES*. Repeat Step5.
  - -If $BS = 180°$, determine T_x, T_y, and *ES*. If $ES = 90°$, proceed to Step6.

  Otherwise, stop (infeasible posture).

Step6. Determine *AV*.

Step7. Check *AV*.

- If $AV \leq 10°$, determine the viewing distance *VD*.

  - If $38 \leq VD \leq 62$ cm, go to Step16.

  Otherwise, proceed to Step8.
- If $AV > 10°$, proceed to Step8.

Step8. Set $VD = 62$ cm and $AV = 10°$. Then, determine T_x and T_y.

Step9. Set $ES = 90°$. Then, determine B_x and B_y.

Step10. Find *E* as an intersection point of two circles where

- Circle 1 has its center at point *P* and its radius of *UA* from Step1.
- Circle 2 has its center at point *Q* and radius equal to the distance from *B* to *E*.

Step11. Determine *AB*.

Step12. Determine W_x, W_y, M_x, M_y, R_x, R_y, F_x, and F_y.

Step13. Determine *AS* (from *H*, *S*, and *E*).

Step14. Check *AS*.

- If $AS \leq 20°$, go to Step16.
- If $AS > 20°$, proceed to Step15.

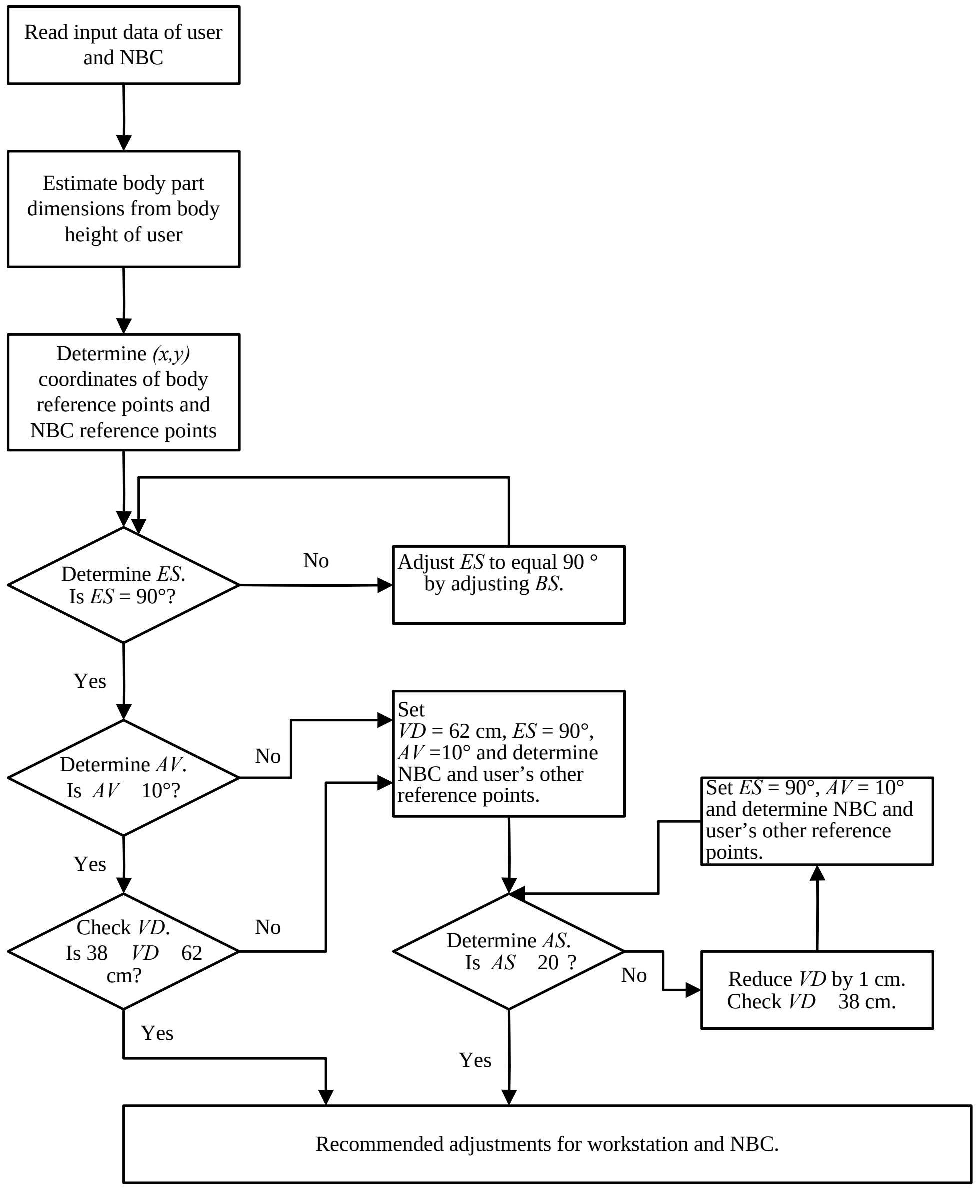


Figure 4.8 Flowchart of the Algorithm Without Workstation Constraints

Step15. Decrease *VD* by 1 cm. Then, check the new *VD*.

- If *VD* > 38 cm, determine T_x and T_y. Repeat Step9 – Step14.
- Otherwise, stop (infeasible posture).

Step16. The compromised body posture, recommended seat height, recommended worksurface height, tilt angle of the base unit, and screen angle are obtained.

4.4.2 Algorithm with Workstation Constraints

When the NBC user is obliged to work at a workstation with specific seat and work surface heights, the second algorithm will compute how the seat and work surface heights should be adjusted. If necessary, a footrest of certain height will also be recommended.

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This algorithm functions in the following manner. Initially, the first algorithm (in Section 4.4.1) is used to determine the adjustment recommendations without workstation constraints. So the first three stages of functionality are indifferent. Some further functions are done after completing Stage 3.

Stage 4: The recommended seat height *HH* and work surface height (as determined from the *y*-coordinate of the front edge of the base unit F_y) are then compared to the actual seat height *AHH* and work surface height *AWH*, respectively. The comparison results will fall in one of the following nine conditions.

Condition 1: $HH = AHH$, $F_y = AWH$
Condition 2: $HH = AHH$, $F_y > AWH$
Condition 3: $HH = AHH$, $F_y < AWH$
Condition 4: $HH > AHH$, $F_y = AWH$
Condition 5: $HH > AHH$, $F_y > AWH$
Condition 6: $HH > AHH$, $F_y < AWH$
Condition 7: $HH < AHH$, $F_y = AWH$
Condition 8: $HH < AHH$, $F_y > AWH$
Condition 9: $HH < AHH$, $F_y < AWH$

Then, the algorithm will give the adjustment recommendations that satisfy the workstation constraints.

The functions of Stage 4 are executed in 12 steps which are continued after completion of Step16. Step1 to Step16 for this algorithm is identical to the previous algorithm. Figure 4.9 presents the flowchart from step17 to step28.

Adjustment Procedure:

Step17. Compare *HH* to *AHH* and F_y to *AWH*.

- If $HH = AHH$, $F_y = AWH$, set condition = 1.
- If $HH = AHH$, $F_y > AWH$, set condition = 2.
- If $HH = AHH$, $F_y < AWH$, set condition = 3.
- If $HH > AHH$, $F_y = AWH$, set condition = 4.
- If $HH > AHH$, $F_y > AWH$, set condition = 5.
- If $HH > AHH$, $F_y < AWH$, set condition = 6.
- If $HH < AHH$, $F_y = AWH$, set condition = 7.
- If $HH < AHH$, $F_y > AWH$, set condition = 8.
- If $HH < AHH$, $F_y < AWH$, set condition = 9.

Step18. For condition = 1, no adjustments are required. Go to Step27.

Step19. For condition = 2:

- Add base support = $HH – AWH$.
- Go to Step27.

Step20. For condition = 3:

- Add seat support = $AWH – HH$.
- Add footrest = $AWH – HH$.
- Go to Step27.

Step21.For condition = 4:

- Add seat support = $HH – AHH$.
- Go to Step27.

Step22. For condition =5:

- Add seat support = $HH – AHH$.
- Add base support = $F_y – AWH$.
- Go to Step27.

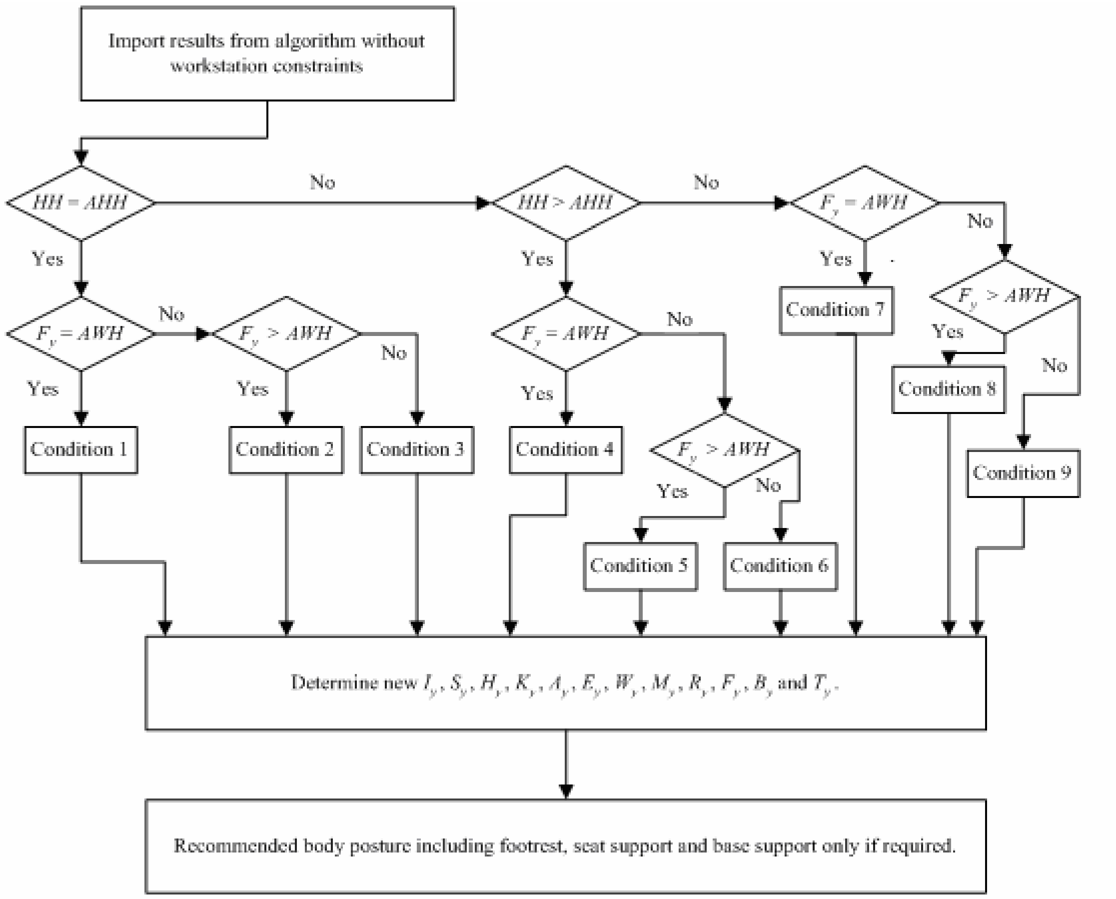


Figure 4.9 Flowchart of Step17 to Step28 of the Algorithm With Workstation Constraints

Step23. For condition = 6:

- Add seat support = (HH – AHH) + (AWH – F_y).
- Add footrest = AWH – F_y.
- Go to Step27.

Step24. For condition = 7:

- Add footrest = AHH – HH.
- Add base support = AHH – HH.

Step25. For condition = 8:

- Add footrest = AHH – HH.
- Add base support = (AHH – HH) + (F_y – AWH).
- Go to Step27.

Step26. For condition = 9:

- Add footrest = AHH – HH.
- Determine the revised F_y.
  -If the revised F_y = AWH, go to Step27.
  -If the revised F_y > AWH, add base support = the revised F_y - AWH
  -If the revised F_y < AWH,
  Add seat support = AWH – the revised F_y.
  Add additional footrest = AWH – the revised F_y.
- Proceed to Step27.

Step27. Determine the revised I_y, S_y, H_y, K_y, A_y, E_y, W_y, M_y, R_y, B_y, and T_y.

Step28. The compromised body posture, recommended seat height, recommended worksurface height, tilt angle of the base unit, screen angle, recommended heights of footrest, seat support, and base support are obtained.

CHAPTER 5

DECISION SUPPORT SYSTEM FOR RECOMMENDING NOTEBOOK COMPUTER AND WORKSTATION ADJUSTMENT (*PostureAdjuster*)

This chapter describes *PostureAdjuster*, a decision support system to recommend necessary adjustments for an NBC and workstation so that the NBC user can assume a correct work posture during NBC operation. *PostureAdjuster* consists of databases, computing algorithms, and user-system interface. Body dimensions, NBC dimensions, NBC angles, NBC-body distance, workstation dimensions, and seat adjustability are the input data needed for computing the work posture. *PostureAdjuster* is able to compute current work posture based on the given data, and recommend ergonomic work postures both with and without workstation constraints. After computation, the outputs include body joint angles, viewing distance, incidence angle, NBC – body distance, NBC settings (and support), and workstation settings (and supports). In addition, a graphical display of body posture is also shown. All the outputs can be printed out as hardcopy.

This chapter is organized as following: firstly, the conceptual design of *PostureAdjuster* is described, followed by, the presentation of its four modules, namely, database, input, computation, and output module. The third section presents the features and user interface of *PostureAdjuster*.

5.1 Conceptual Design

The concept of designing *PostureAdjuster* could be divided in its functionality, usability and practicality.

5.1.1 Functionality

PostureAdjuster is developed to provide with necessary quantitative recommendations. It uses the two analytical algorithms and performs computations and provides the users with only the necessary quantitative data in the recommendation which the user can follow. For advanced users with ergonomics background, it provides access to its databases to add, delete and modify data.

5.1.2 Usability

Even though *PostureAdjuster* has two algorithms to do the computations, a user-friendly interface assists the users to use *PostureAdjuster* who has no prior knowledge about the algorithms. The users are not required to know how the algorithms work- they need to simply provide the inputs required by the algorithms. These inputs are taken from the user through the user-interface and then passed on to the computing algorithms, at the end of computation the results from the algorithm are again presented through the user-interface. Inputs are divided into steps and diagrams with explanations to guide the users. The output screen also has a print option to make a hard copy of the recommendation.

5.1.3 Practicality

PostureAdjuster is intended to be freely distributable. For ease of use, it was aimed that the users should not have critical system requirements or to install any programs, or to connect with internet while using it. It is built in Java programming language. The reasons behind this were Java can create database, calculations can be performed in java and professional quality user-interface can be built in java. As a result there were no dependencies on other programs especially for the database part and a stand-alone application *PostureAdjuster* is built. Moreover, java is free to use and any application built in java is freely distributable by law. Java is commonly used on every computer since all computers use applications that are built in java. In addition, any application built in java is platform independent- can be run on windows, unix/linux and Mac. For a computer without Java, it takes less than 5 minutes to install Java freely from the web.

5.2 Modules

PostureAdjuster consists of databases, computing algorithms and user-system interfaces- all of which are built using Java programming language. In the previous section the conceptual design is presented. *PostureAdjuster* is divided into four modules, namely, the database module, input module, computation module and output module. To view these modules in the conceptual design view such as the previous section, it can be said that, the database module is the database part, computation module is the computing algorithms part and the input and output module belongs to the user-interface part. Below each of these four modules are presented in details. Figure 5.1 presents the conceptual design and dataflow between the modules in *PostureAdjuster*.

5.2.1 Database Module

PostureAdjuster consists of three databases, namely, anthropometric database, notebook computer database, and workstation database. The three databases are briefly described below.

Anthropometric Databases

The anthropometric database consists of six different databases. There are three databases for male with body height of 5th percentile, 50th percentile, 95th percentile and another three databases for female 5th percentile, 50th percentile, 95th percentile. Each of these six anthropometric databases contains anthropometric data of selected body parts or body segment lengths expressed as percentages (proportions) of the NBC user's body height. There are eight lengths to be stored in these databases, which are:

(1) Eye height (seated) *IH*,
(2) Shoulder height (seated) *SH*,
(3) Length of upper arm *UA*,
(4) Length of lower arm *LA*,
(5) Length of hand *HA*,
(6) Popliteal height (seated) *HH*,
(7) Length of upper leg *UL*, and
(8) Length of lower leg *LL*.

All dimensions in the anthropometric databases are measured in centimeters (cm). The data are utilized by the adjustment algorithms to determine the estimated lengths of body parts based on gender and body height. At present, the anthropometric data of Thai population is stored in the database (Thai Industrial Standards Institute, 2001). When *PostureAdjuster* is to be used for other user populations, new set of body part proportions can be stored so that the recommendations will be appropriate for intended NBC users.

Notebook Computer Database

The notebook computer database contains all required information on NBC. Six data per notebook computer is stored in this database. They are:

(1) Brand name,
(2) Model,
(3) Screen size (measured in inches),
(4) Row-length,
(5) Screen-length, and
(6) Base-length

All dimensions except the screen size are measured in centimeters. Additionally, photographs of NBCs are also stored in the database to assist the user to select the right NBC. Including photographs there are seven data of each NBC to be stored in this database.

Workstation Databases

The workstation databases contain two databases which are:

(1) Table or work surface database, and
(2) Chair or seat database

Information of tables and chairs where NBC users are most likely to operate an NBC are stored. Examples are general-purpose table, writing desk, computer table, meeting table, dining table, cafeteria table, non-adjustable chair, adjustable chair, stool, classroom chair (with writing board), etc. Their photographs are also stored along with the work surface height and seat height. For each table or chair the data to be stored are the description, height and an image. The height is measured in centimeters.

5.2.2 <u>Input Module</u>

The input module of *PostureAdjuster* is conceptually a part of the user-interface. The input module helps the users to choose the appropriate options during entering data. Namely, it consists of checkboxes, text field boxes, drop-down menus and buttons to operate through the databases thus assisting the user to completely enter all required fields that are necessary for the computing module of *PostureAdjuster*.

There are two ways that the inputs could be provided. Some inputs can be directly inserted in the text fields and also they could be selected from the stored databases. For example, data about NBC could be chosen from existing database or they can be entered in the text field. In the first case, the input module goes in the database but only displays the necessary data to the user that assists the user to identify the type of NBC. When the NBC is chosen the required dimensions of that particular NBC is chosen and sent to the computation module. Similarly, anthropometric data and workstation data can be input in either of the two ways.

The computation module has certain data requirements in order to do a proper computation; the input module makes sure all those required data are provided to the computing module. The input module can interact with databases, obtain data directly from users and then interacts with the computing module. In summary, the input module provides all kind of data from user either through user's direct entry, or presenting users with the databases to select from it and finally collecting all selections or entries of data by user, and passing it to the computing module. A java-script was solely coded for the input module to perform its above functions.

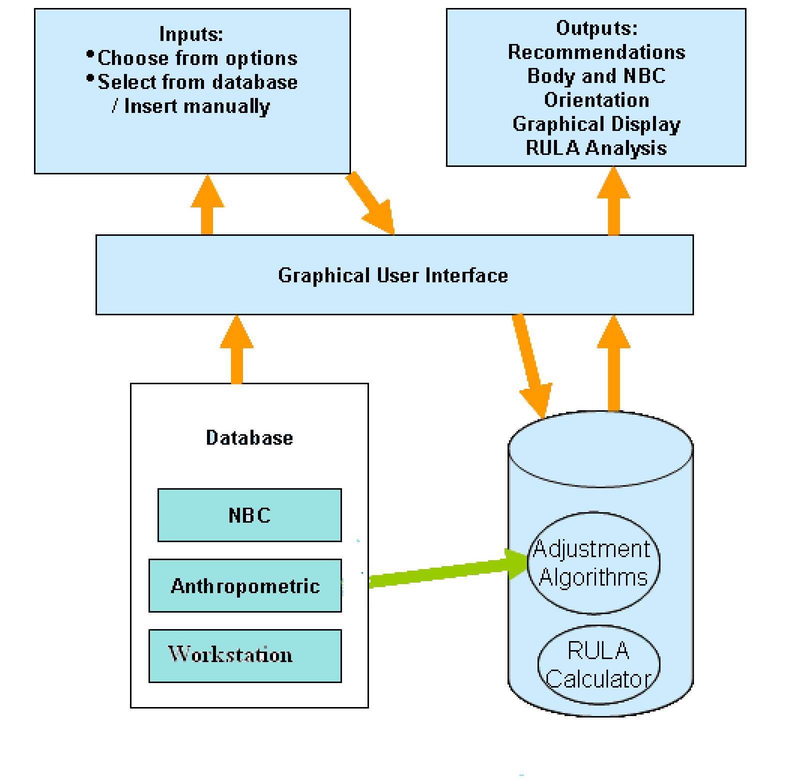


Figure 5.1 Modules and data flow between modules in *PostureAdjuster*

To calculate RULA score, several numeric inputs are required. The input module also collects these numeric inputs through the user interface (details in section 5.3.3), passes it to the RULA calculator in computation module.

5.2.3 Computation Module

The computation module of *PostureAdjuster* is the part that does all analytical and mathematical calculations. It is equipped with two adjustment algorithms, namely, the algorithm without workstation constraint and the one with workstation constraint. In the first algorithm, it is assumed that there are no workstation constraints. That is, the algorithm freely positions the body and the NBC to form the work posture recommended for NBC operation, and provides the coordinates of all reference points and body joint angles as the outputs.

The second algorithm considers two constraints of the workstation, namely, seat height and work surface height. Firstly, the algorithm imports the resulting reference point coordinates and joint angles from the first algorithm. From the recommended and actual seat and work surface heights, nine possible adjustment scenarios can be defined. The algorithm determines which scenario exists and recommends the footrest, seat support, and NBC base support for assuming the recommended work posture.

The computation module also consists of formulas. One set of formulas are used to estimate the eight body dimensions,(the seated eye height, seated shoulder height, seat height, upper-arm length, lower-arm length, hand length, upper-leg length, lower-leg length) from the body height. Another set of formulas are there to estimate necessary dimensions (row-length, screen-length, base-length) of a NBC by using only its screen-size.

For more details on the adjustment algorithms, see Jalil and Nanthavanij (2007). Both these algorithms have some output results. These results are the final output of the computation module. In summary, the computation module feeds on the data provided by the input module, performs computation and then provides the results which are only some numerical values. Some of these numeric values are lengths, some are angles and some are coordinates of necessary reference points on the x-y axis.

In addition, the computation module also has a RULA calculator which calculates RULA score. Note that, the RULA calculator is an independent component in the computation module and has no interaction with any databases or adjustment algorithms. This part consists of three tables provided by RULA and numerous logic statements that help to read the three tables in the correct manner, obtain scores from each table, add them and thus calculate the RULA Grand Score.

5.2.4 Output Module

Alike the input module in section 5.2.2 the output module of *PostureAdjuster* is conceptually a part of the user-interface. *PostureAdjuster* is designed in such a way that it would provide summarized necessary recommendations or evaluations, to the users regarding NBC and workstation adjustments and also provide a graphical image of the recommended posture.

The output module starts acting after the computation module finishes its work. The computation module has numeric values at the end of its work process. The output module reads each of those numeric values and does three functions. Firstly it formats the numeric values so that they are not more than 2 digits after the decimal values. Secondly, it reads through each numeric value to recognize its identity whether it is a length, an angle or a coordinate of some reference point. After the identification it presents them as description in the output parts of the user interface which is understandable by users. Thirdly, it also plots each of the coordinates on the x-y plane and joins them appropriately through a line so that it forms a simple side-view of a user, NBC and workstation.

In summary, the output module uses the results of the computation module, formats them, presents them in the user interface as description and provides an image. A java script has been coded to perform these tasks of the output module.

5.3 Features and User Interface

Initially, the user is greeted by the welcome screen as in Figure 5.2. The task bar on the top of the screen shows task options for *PostureAdjuster*. They are grouped into adjust posture, RULA analysis, manage posture and help. In the adjust posture group, the user can select whether to evaluate his/her current work posture at the NBC workstation. Essential information is asked in the specially-designed screen and the line figure of the user's body posture is displayed. Additionally, the user can choose to have the program recommend the correct seated posture and necessary adjustments based on his/her NBC and workstation data by choosing recommend ergonomic work posture. In the RULA analysis part users can analyze their work posture and get a RULA score which states how injury-prone the posture of the user is. In the database management part, the user can add remove new data.

Figure 5.2 Welcome Screen of *PostureAdjuster*

5.3.1 Evaluation of Current Work Posture

Evaluation of current work posture allows the NBC users to evaluate a certain posture the user might have adopted or plans to adopt. There are some inputs that need to be selected to do this evaluation.

The evaluation of current work posture is the first option that comes under the menu from the taskbar named “Adjust Posture” as shown in Figure 5.3. Upon choosing this option the screen would appear. This screen helps to collect inputs, which are functions of the input module earlier mentioned in section 5.2.2. To keep this screen user-friendly and succinct, all the inputs asked are kept in one-screen. The inputs can be entered by the users in four steps which are guided in the screen as shown in Figure 5.4.

Step 1: The user has to make a selection of the gender and enter the body height in centimeters by manually typing numeric keys. Next the input asks about body segment lengths which are namely, the seated eye height, seated shoulder height, seat height, upper-arm length, lower-arm length, hand length, upper-leg length and lower-leg length. These segment lengths could be estimated by formulas that exists in the computation module of *PostureAdjuster* or could be directly input one by one. In this step, the user can also choose whether to estimate or directly insert these values. In case of directly inserting the values, all eight inputs are shown in images in the right box beside the inputs where each image appears as the mouse pointer is placed on each input text field. This helps the user to comprehend the inputs easily.

Step 2: This step collects information about NBC orientation. Three inputs are required at this step. The base angle (*AB*), the base-screen angle (*BS*) and a distance between the front edge of the NBC base-unit and the front of chest are the three required inputs. All three inputs are shown in images in the right box, where each image appears while the mouse pointer is placed on each input text field. This helps the user to comprehend the inputs easily

Figure 5.3 Choosing Evaluate Current Work Posture from Adjust Posture menu

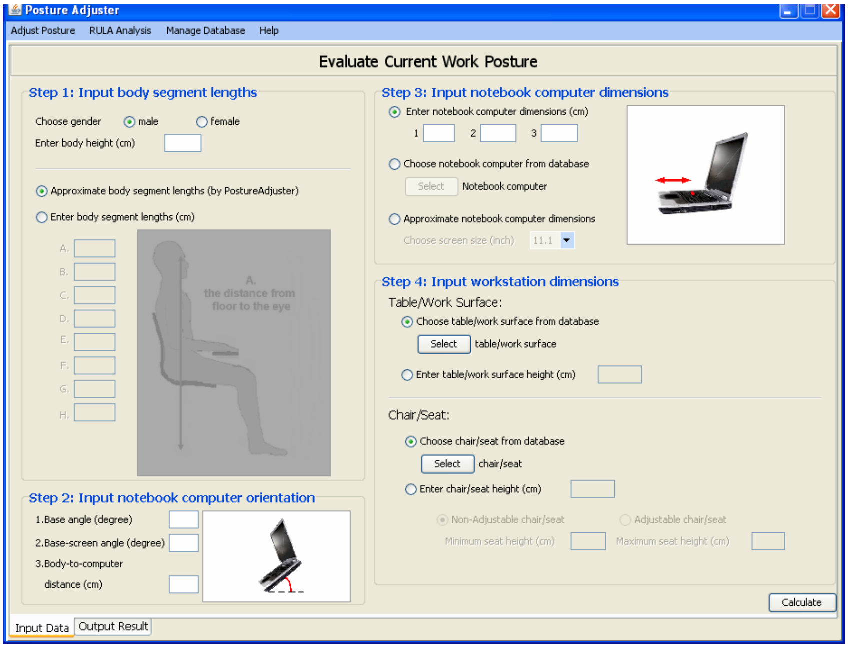


Figure 5.4 Evaluate Current Work Posture Screen with its Four Steps

Step 3: This step is to collect information about NBC dimensions. Three inputs are required at this step from the user, namely the row-length, screen-length and base-length. These inputs can be inserted in three ways. In the first way they could be directly inserted. In this case, the images for them will appear in the right box, where each image appears while the mouse pointer is placed on each input text field. This helps the user to comprehend the inputs easily. In the second way, the NBC could be directly chosen from the stored database. An additional window pops up, as shown in Figure 5.5, when this option is chosen and the select button is pressed. This additional window presents model, brand name, screen size and the image of NBCs currently present in the database. The image has a larger preview on the right hand side which gives a clearer view of the NBC. The third way is to find the three dimensions by estimation only from its screen size. These formulas exist in the computational module. To choose the screen size a drop-down menu is available as shown in Figure 5.6.

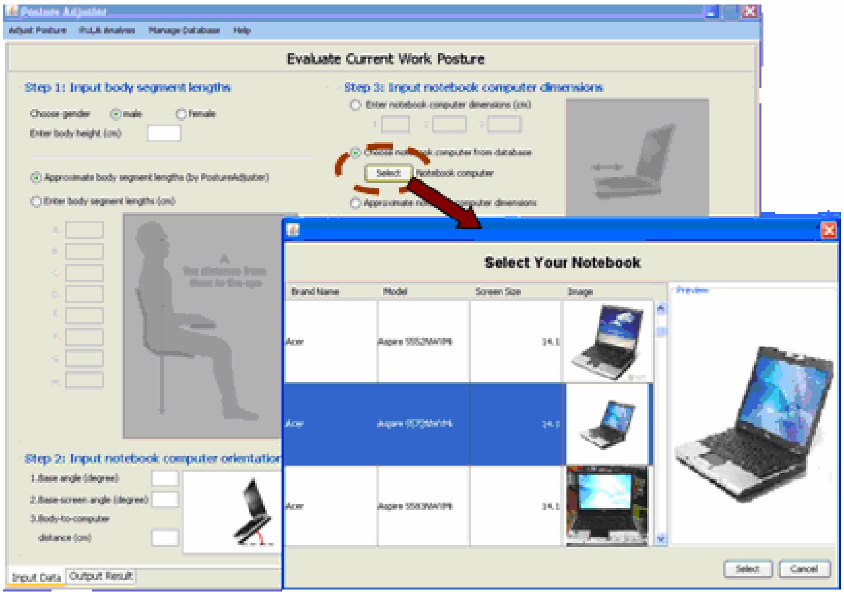


Figure 5.5 Selecting NBC from the Database

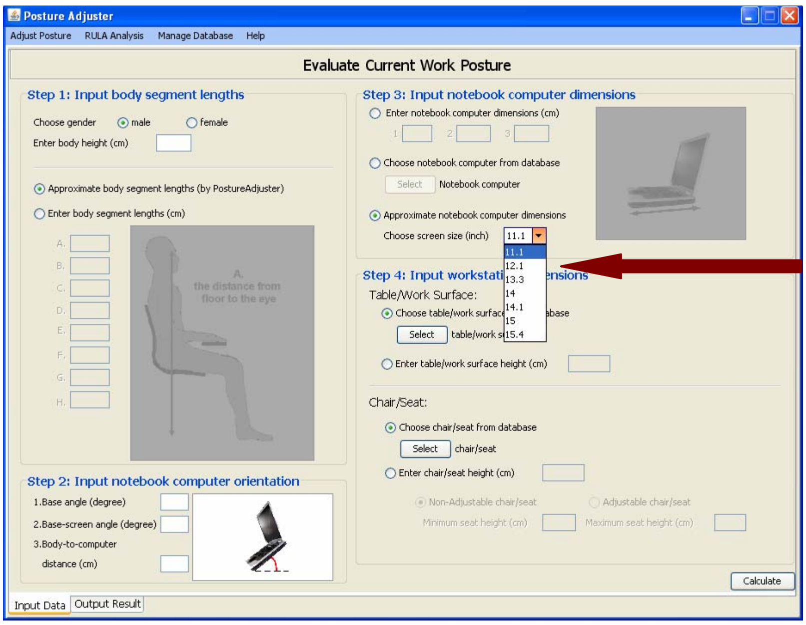


Figure 5.6 Drop down menu to choose NBC screen size

Step 4: This is the final step for inputs. This step collects inputs regarding workstation. A workstation consists of a table or work surface and a chair or seat. Firstly the input regarding the work surface or table is collected. Only the height of the table or work surface is required which can be entered directly by typing numeric key values or can be chosen from the database. An additional window pops up when this option is chosen and the select button is pressed. This additional window presents description and the image of the work surface currently present in the database as shown in Figure 5.7. The image has a larger preview on the right hand side which gives a clearer view of the work surface.

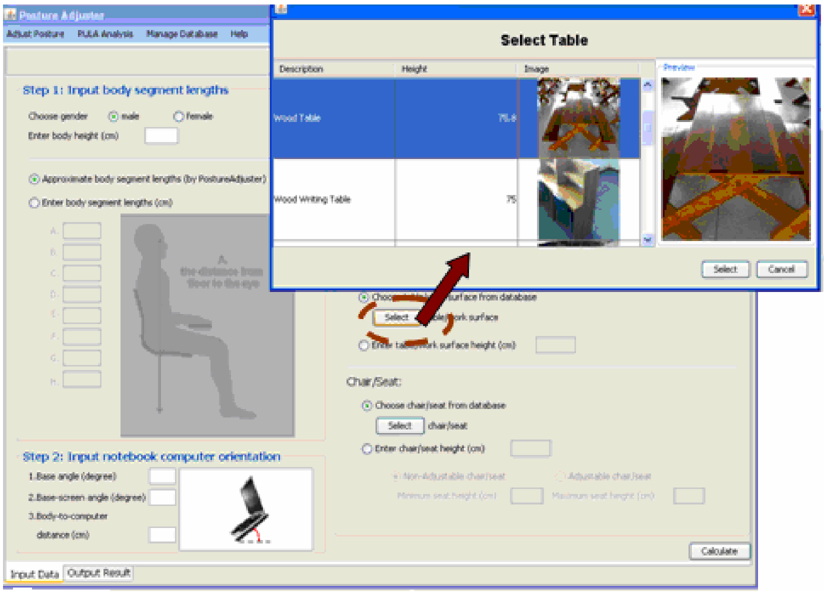


Figure 5.7 Selecting Table or Work surface from database

Next the input regarding the chair or seat is collected. Only the height of the chair or seat is required which can be entered directly by typing numeric key values or can be chosen from the database. An additional window pops up when this option is chosen and the select button is pressed. This additional window presents description and the image of the seat currently present in the database. The image has a larger preview on the right hand side which gives a clearer view of the seat as shown in Figure 5.8. The chair or seat is categorized by its adjustability. For non-adjustable seats no additional data is required. In case of adjustable seats two more additional inputs are required which are the minimum height and the maximum height of the seat.

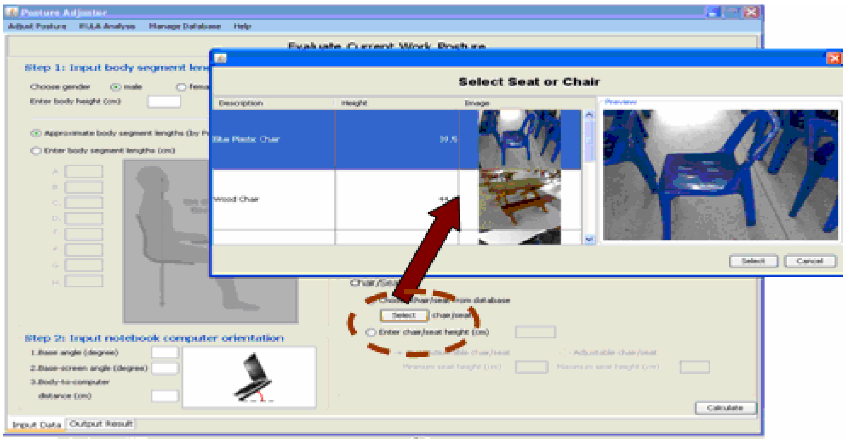


Figure 5.8 Selecting Chair or Seat from database

At the end of step 4, the next step is to click on the calculate button. The output would be presented in the next screen. On the left-hand panel of the output are the summarized values and the right hand side is a panel which is blank initially as shown in Figure 5.9. In this window the user can click on the here button to choose and display an image of the posture that they are evaluating which has been taken earlier. The image on the right and the summarized data on the left would depict a better evaluation of the current posture, shown in Figure 5.10.

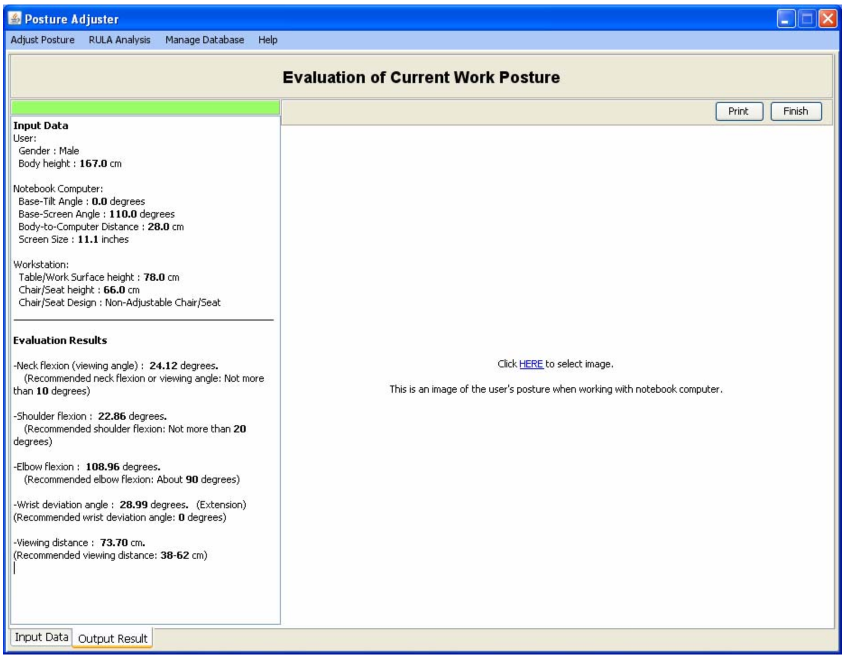


Figure 5.9 Output screen of Evaluation of Work Posture

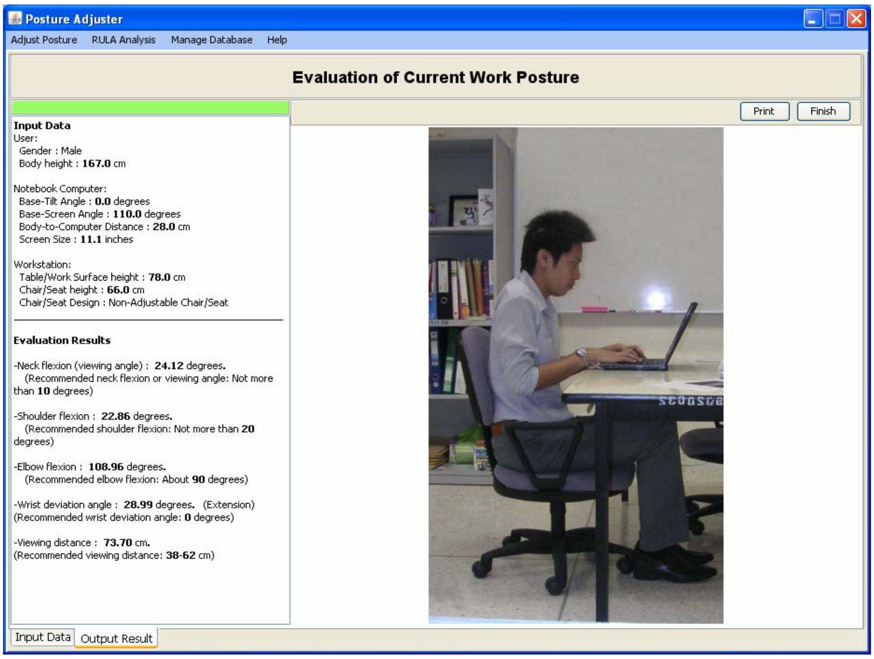


Figure 5.10 Choosing an image to be displayed on the Evaluation Output

The summarized data on the left panel is divided into two parts. The top part repeats the inputs. This data about inputs is categorized as user, NBC and work station. The user data consists of the user's gender, body height. The NBC data consists of base angle, base-screen angle, body-to-NBC distance and the screen size of the NBC. The work station data shows the table or work surface height, the chair or seat height and the type of chair or seat. Incase of an adjustable chair, the information additionally shows the minimum and maximum heights.

The bottom part of the summarized data shows the evaluation of the current posture. It provides with numbers that show the amount of neck flexion, shoulder flexion, elbow flexion, wrist deviation and the viewing distance. In case of the wrist deviation it also mentions whether it is an extension or a flexion. Below each of these numbers, the recommended level of deviations allowed for the neck, shoulder, elbow, wrist and the viewing distance that are allowed by ergonomics guidelines are also provided so that the user can compare the differences with the evaluation results.

At the end of the evaluation the user can click the print button to print a copy of the evaluation shown is Figure 5.11. After completion, the user can click finish button which takes them back in the welcome screen.

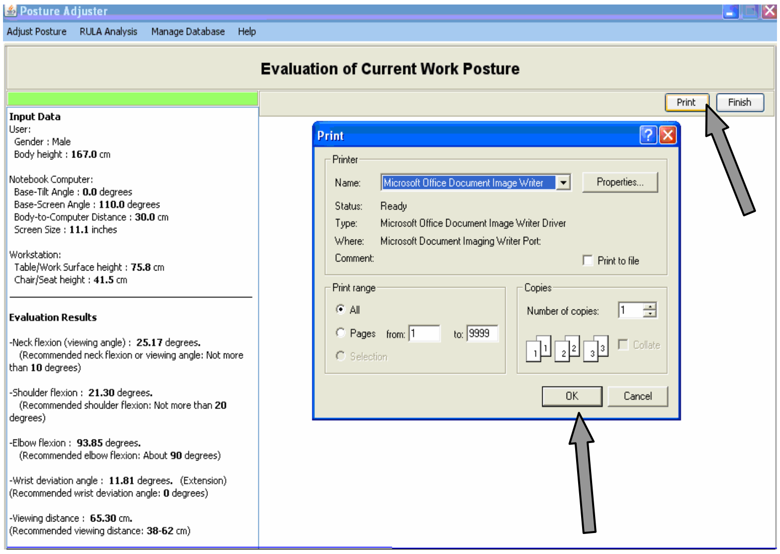


Figure 5.11 Printing the Output

5.3.2 Determination of Ergonomic Work Posture

Determination of ergonomic work posture is the perhaps the essence of *PostureAdjuster*, it is the main contribution of this research. This feature in the program gives recommendations on how to set up NBC and work station settings in terms of NBC opening angle, tilt angle of the base unit, base support, work surface height, seat height, seat support, foot rest-so that the user can simply follow those guidelines to maintain a good posture during NBC operation.

The recommend ergonomic work posture is the second option that comes under the menu from the taskbar named "Recommend Ergonomic Work Posture" as shown in Figure 5.12. Upon choosing this option the screen would appear. This screen helps to collect inputs, which are functions of the input module earlier mentioned in section 5.2.2. To keep this screen user-friendly and succinct, all the inputs asked are kept in one-screen. The inputs can be entered by the users in four steps which are guided in the screen. The input screen is shown in Figure 5.13. Some figures concerning selection from a database, selection from drop down menu, printing the output are not shown in this section due to their similarity with the previous section.

Step 1: In this step the user has to make a selection of the adjustment type. There are two type of adjustments namely, the adjustment without work station constraints and the adjustment with workstation constraints. The first adjustment is selected when a user would like to know the ergonomic recommendations and does not have a fixed table or chair to sit on yet. So there is no constraint of work station, the user can see the recommendation and obtain table and chair based on that recommendation. If this type of adjustment is selected the algorithm in section 4.4.1 is utilized and since there would be no work station constraints so the Step 4 of the input is automatically disabled in order to prevent users from inserting any data about workstation by mistake. The second type of adjustment is selected when a user already has a table and a chair and those cannot be altered. In that case there are constraints imposed on the recommendations of the work station and NBC adjustment, so the recommendations provided are based on the existing work station of the user. This case is more pragmatic since most users already own a table and a chair and they would like to use that but maintain a good posture. If this type of adjustment is selected the algorithm in section 4.4.2 is utilized.

Figure 5.12 Choosing the Recommend Ergonomic Work Posture feature

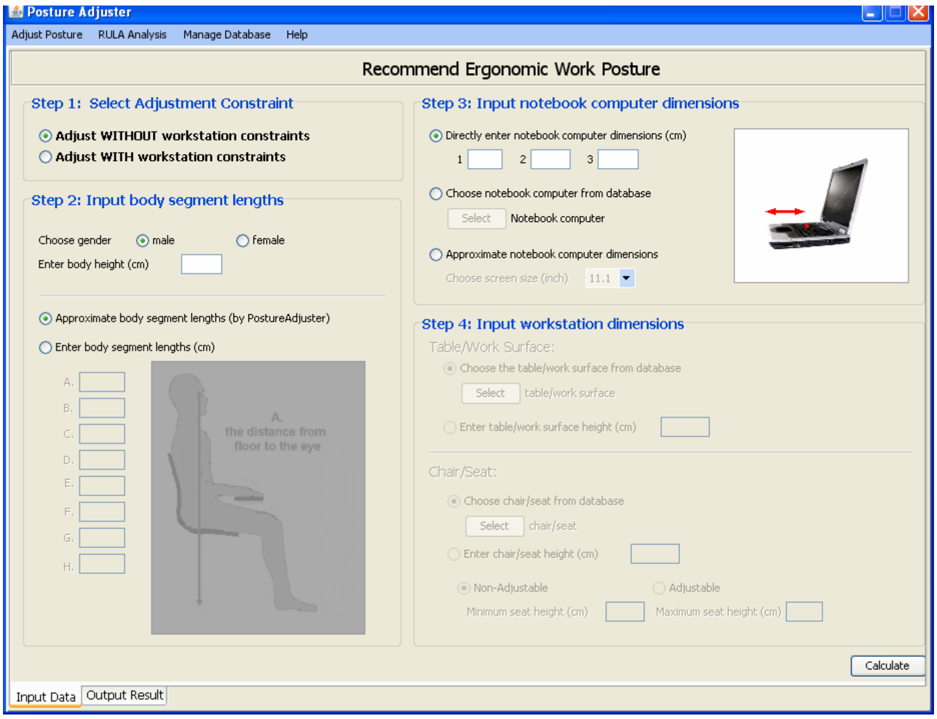


Figure 5.13 The Input screen with four steps of Recommend Ergonomic Work Posture

Step 2: In the second step user is required to fill in information about body segment lengths.The user has to make a selection of the gender and enter the body height in centimeters by manually typing numeric keys. Next the input asks about body segment lengths which are namely, the seated eye height, seated shoulder height, seat height, upper-arm length, lower-arm length, hand length, upper-leg length and lower-leg length. These segment lengths could be estimated by formulas that exists in the computation module of *PostureAdjuster* or could be directly input one by one. In this step, the user can also choose whether to estimate or directly insert these values. In case of directly inserting the values, all eight inputs are shown in images in the right box beside the inputs where each image appears as the mouse pointer is placed on each input text field. This helps the user to comprehend the inputs easily.

Step 3: This step is to collect information about NBC dimensions. Three inputs are required at this step from the user, namely the row-length, screen-length and base-length. These inputs can be inserted in three ways. In the first way they could be directly inserted. In this case, the images for them will appear in the right box, where each image appears while the mouse pointer is placed on each input text field. This helps the user to comprehend the inputs easily. In the second way, the NBC could be directly chosen from the stored database. An additional window pops up when this option is chosen and the select button is pressed. This additional window presents model, brand name, screen size and the image of NBCs currently present in the database. The image has a larger preview on the right hand side which gives a clearer view of the NBC. The third way is to find the three dimensions by estimation only from its screen size. These formulas exist in the computational module. To choose the screen size a drop-down menu is available.

Step 4: This is the final step for inputs. This step collects inputs regarding workstation. A workstation consists of a table or work surface and a chair or seat. By default this part of the input screen is disabled. It is enabled only when a user selects the adjustment with work station constraints option. This measure was taken to prevent users who choose the adjustment without work station constraints to not insert any work station data since work station data is not required for that type of adjustment.

Firstly the input regarding the work surface or table is collected. Only the height of the table or work surface is required which can be entered directly by typing numeric key values or can be chosen from the database. An additional window pops up when this option is chosen and the select button is pressed. This additional window presents description and the image of the work surface currently present in the database. The image has a larger preview on the right hand side which gives a clearer view of the work surface.

Next the input regarding the chair or seat is collected. Only the height of the chair or seat is required, which can be entered directly by typing numeric key values or can be chosen from the database. An additional window pops up when this option is chosen and the select button is pressed. This additional window presents description and the image of the seat currently present in the database. The image has a larger preview on the right hand side which gives a clearer view of the work surface. The chair or seat is categorized by its adjustability. For non-adjustable seats no additional data is required. In case of adjustable seats two more additional inputs are required which are the minimum height and the maximum height of the seat.

At the end of step 4, the next step is to click on the calculate button. The output would be presented in the next screen, as shown in Figure 5.14. On the left-hand panel of the output are the summarized data and on the right hand side is an image of the recommended posture. The summarized data on the left panel is divided into two parts. The top part repeats the inputs. This data about inputs is categorized as type of adjustment, user, NBC and work station. The type of adjustment tells if the adjustment was without or with workstation constraints. The user data consists of the user's gender, body height. The NBC data consists of base angle, base-screen angle, body-to-NBC distance and the screen size of the NBC. The work station data shows the table or work surface height, the chair or seat height and the type of chair or seat. Incase of an adjustable chair, the data additionally shows the minimum and maximum heights.

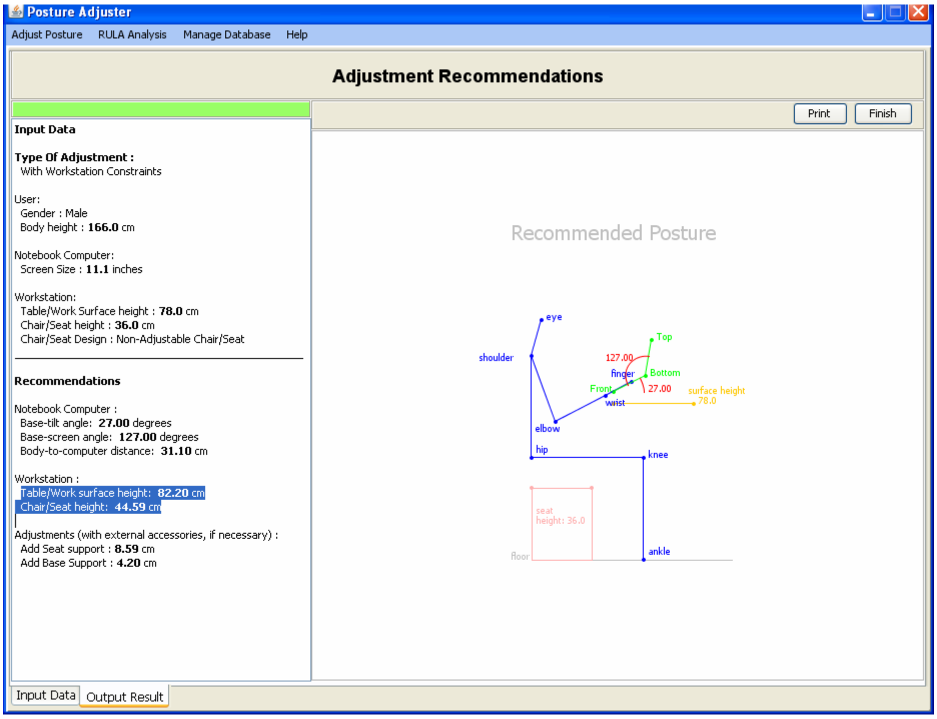


Figure 5.14 Output with Adjustment Recommendations

The bottom part of the summarized data shows the recommendations to obtain an ergonomic work posture. It is divided into three parts namely with recommendation about NBC, work station and additional adjustments, which appears only when the recommendations are found with work station constraints. The NBC part presents the recommended amount of base-tilt angle, base-screen angle and body-to-computer distance. The work station part presents the recommended table or work surface height and chair or seat height. The additional adjustment, which only appears when then recommendations are found for adjustment with work station constraints, provides recommendation of base support for the NBC, seat support and foot rest for the user, only if required.

On the right hand side of the output screen is the image presented of the recommended posture. This image consists of a user's body, NBC, work surface and seat. The image is plotted from the outputs of the algorithms that was performed in the computation module of *PostureAdjuster*. All coordinates of users body reference points, NBC reference points and work station height is obtained at the end of computation module and plotted on this screen. Then they are joined to obtain the user, NBC and work station presented in this image. This image can help the users to have a clear understanding of the recommended posture.

At the end of the obtaining recommendations, the user can click the print button to print a copy of it. After completion, the user can click finish button which takes them back in the welcome screen.

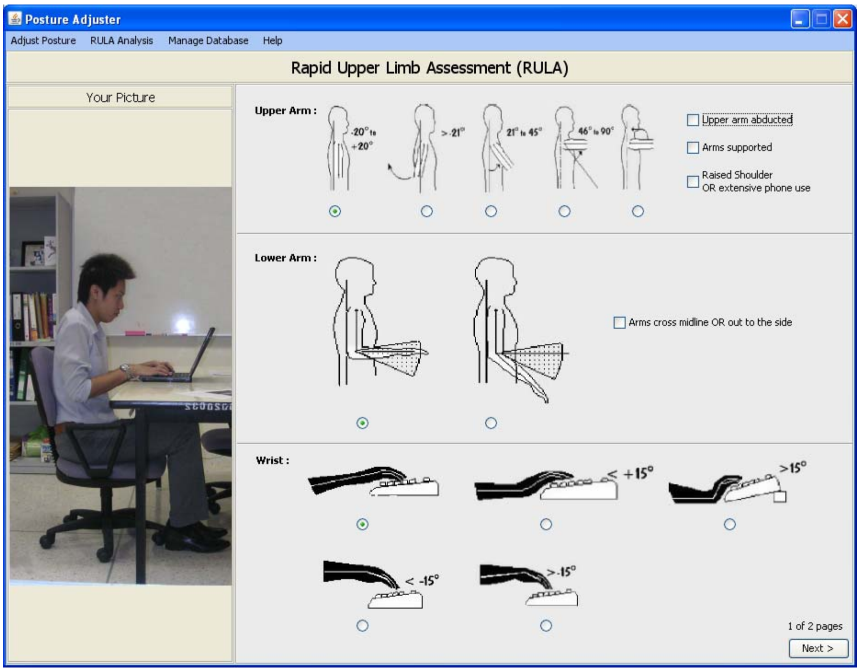
5.3.3 Analysis of Work Posture

The analysis of work posture is a feature that helps users to analyze a work posture and use RULA (Rapid Upper Limb Assessment) to see a score and obtain an action level. The RULA score tells how injury prone the user is while using computer in a certain posture. The higher the score is the more injury prone that posture is. An action level of RULA tells gives an advice for the user about that working posture.

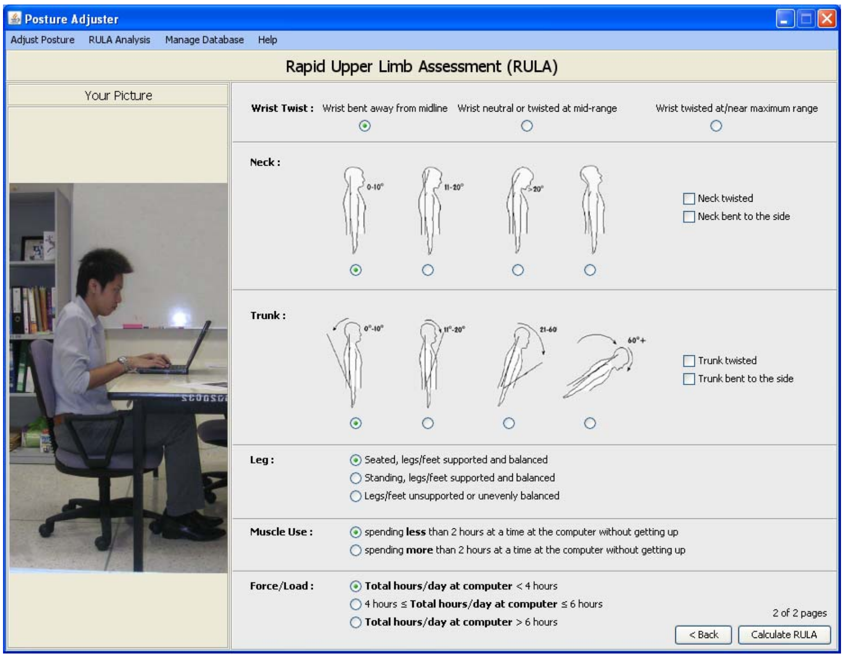
The analysis of the work posture can be done by selecting the RULA analysis menu from the taskbar as shown in Figure 5.15. Inputs regarding upper arm, lower arm, wrist, wrist-twist, neck, trunk, leg, muscle use and force/load are required to calculate RULA score. These inputs are collected through two continuous screens in the user-interface. Initially there is the first screen. The screen is divided into two panels like Figure 5.16(a). On the left hand side panel is a blank space which can be filled in with a user's image. This image would be the side view of the user operating a computer. On the right hand side are RULA inputs presented with posture images and sometimes descriptions of the posture condition of that certain part of the body. The first screen starts with posture images of upper arm, lower arm and the wrist. The user can make selection by comparing with the image on the left hand side. In case the user has no image, the user can make a judgement from memory. When the first three inputs are entered the user can click the next button to move on to the second input screen.

Figure 5.15 Choosing the calculate RULA score from RULA Analysis menu

The second input screen, as shown in Figure 5.16(b), also presents a similar view with two panels where the left hand side panel is of the image and the right hand side wider panel, the remaining 6 RULA inputs presented with posture images and sometimes descriptions of the posture condition of that certain part of the body. The inputs are regarding the wrist-twist, neck, trunk, leg, muscle use and force/load. The user has to make selections from different options presented for each part. At the end of this page the user can go back to the previous screen to make any corrections or can calculate RULA score with the button click.



(a) First Input Screen of RULA Analysis



(b) Second Input Screen of RULA Analysis

Figure 5.16 Input Screens of RULA Analysis

In the output screen of the analysis of work posture part, as shown in Figure 5.17, the users are presented with a RULA score. This screen is also divided into two panels where on the left the image is present (if selected at the first page), and on the right hand panel the summarized score. The right hand panel is divided into three areas. The top area shows body part score namely the upper arm score, lower arm score, wrist score, wrist twist score, neck score, trunk score, leg score, muscle use score, force/load score. The bottom area is divided into two parts. The left part shows the RULA grand score. The right part shows the action level. The action level gives advice or comments on the user's posture.

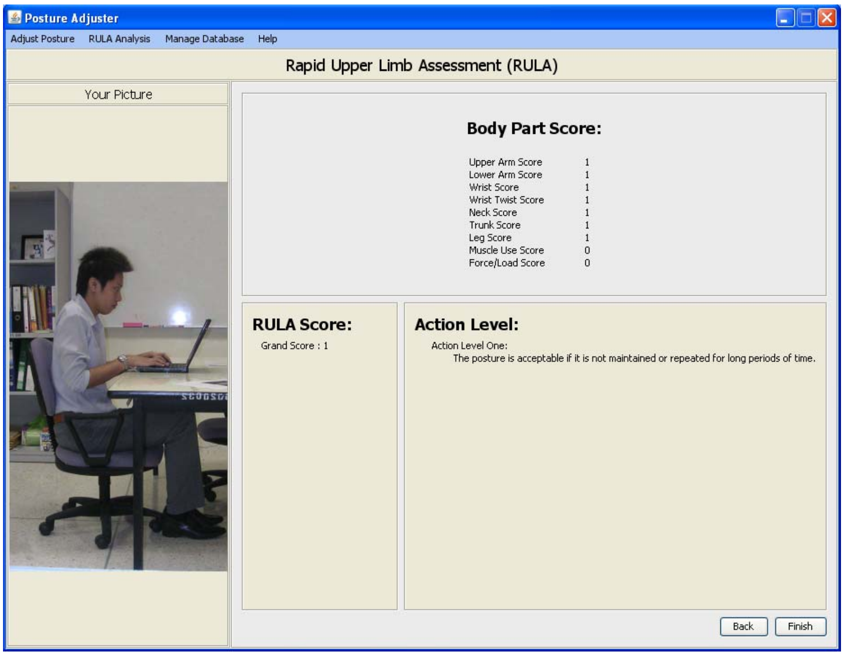


Figure 5.17 Output Screen of RULA Analysis

At the end, the user can use back button to make any small changes in any inputs. Upon completion the user can click on the finish button to go back to the welcome screen.

5.3.4 Database Management

PostureAdjuster consists of databases as mentioned in section 5.2.1. It provides a feature for managing these databases. The databases could be managed by selecting the manage database menu from the taskbar. The databases are restricted only to the users with some ergonomic knowledge or advanced users who are assumed to have comprehended the use of the databases. So it is restricted with a password. Initially the user will be prompted for the password to control access of the databases. Figure 5.18 shows the password prompting window. Any change in the anthropometric databases will change the outcome of the algorithm results thus it will affect the outcome of evaluation of current posture and recommendation of ergonomic work posture features in *PostureAdjuster*. Though all three databases namely, the anthropometric, NBC and workstation can be accessed directly, they are presented in the taskbar menu in the mentioned order.

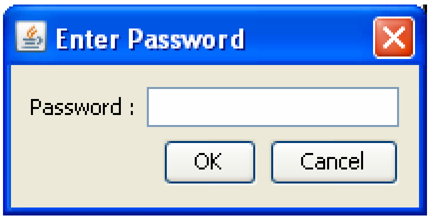
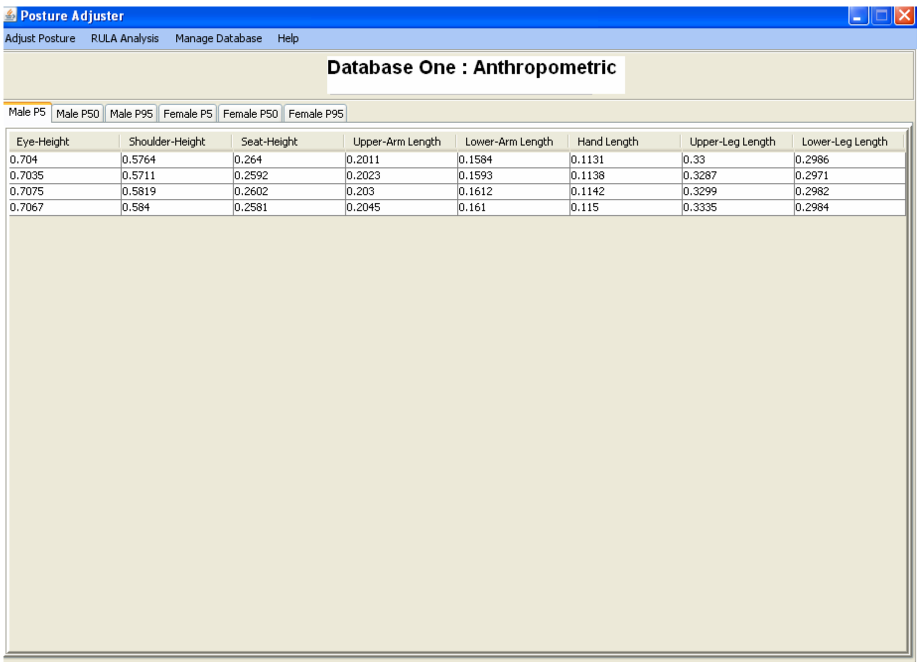


Figure 5.18 Pop up window asking for password to enter the databases

(I). *Management of the Anthropometric Databases*

The anthropometric database is known as the database one. It consists of six databases. There are three databases for male with body height of 5th percentile represented as Male P5, 50th percentile represented as Male P50, 95th percentile represented as Male P95 and another three databases for female 5th percentile represented as Female P5, 50th percentile represented as Female P50, 95th percentile represented as Female P95. These six databases, shown in Figure 5.19, are presented in tabs and clicking upon each tab the user can view the data that belongs to that gender percentile. Each of these six anthropometric databases contains anthropometric data of selected body parts or body segment lengths expressed as percentages (proportions) of the NBC user's body height. There are eight lengths to be stored in these databases namely, the seated eye height, seated shoulder height, seat height, upper-arm length, lower-arm length, hand length, upper-leg length, lower-leg length.



Eye-Height	Shoulder-Height	Seat-Height	Upper-Arm Length	Lower-Arm Length	Hand Length	Upper-Leg Length	Lower-Leg Length
0.704	0.5764	0.264	0.2011	0.1584	0.1131	0.33	0.2986
0.7035	0.5711	0.2592	0.2023	0.1593	0.1138	0.3287	0.2971
0.7075	0.5819	0.2602	0.203	0.1612	0.1142	0.3299	0.2982
0.7067	0.584	0.2581	0.2045	0.161	0.115	0.3335	0.2984

Figure 5.19 Anthropometric Databases

To add a new set of data the add button below has to be pressed. All eight fields have to be filled in here. The data cannot be saved yet. The user has to press the back button and then click the save button to ensure the data is saved. The body segments that are presented in the database have to be expressed as a proportion of the body height. To remove a data a row has to be selected first, the remove button to be clicked next, followed by back button and finally the clicking of save button will ensure the changes. The adding or removing data in the database has been functioned to be done in multiple steps to ensure that no serious changes are occurred by mistake in haste.

Note that, user should be very careful while inserting data in the anthropometric databases because the entries here determine the outcome of the estimation of body segment lengths from a given body height. At present, the anthropometric data of Thai population is stored in the database (Thai Industrial Standards Institute, 2001). It is known that over years, there are changes in the anthropometric data for a particular population, for instance, over another 5 years the anthropometry of thai population will not remain the same. For practicality, this feature is added in *PostureAdjuster* so that in future when changes occur in anthropometric data in Thailand, the new data could be inserted to estimate body segment lengths for that population. Moreover, this feature ensures that *PostureAdjuster* could be used for another population from different country by removing all the current data and adding the anthropometric data of that population. This guarantees usability of *PostureAdjuster* in multiple countries.

(II). *Management of the NBC Database*

Managing the NBC database is similar to that of anthropometric databases. Except, here a user does not have to be concerned about any direct effect of the data on the estimation formulas. A data entered in the NBC database is solely a unique piece of data that expand the data resource but does not involve or influence any result outcome.

Each row in the NBC database consists of seven fields namely the brand name, model, screen-size, row-length, screen-length, base-length and image, shown in Figure 5.20. The addition of a new row is done by clicking the add button and then typing the first six fields from keyboard. To add the image field, they user can click on the image field which pops up a browser that can be used to locate and select the image of the NBC from any location on the hard disk or external drives, shown in Figure 5.21. Note that during entering the fields the program already tells the user the type of data to be inserted for that field. In an exception in the data type entry an error message will appear. The brand name and model are of data type string while the rest are of float data type and the image is an image file with its designated extension. All seven fields have to be filled in here to make a successful addition. The data cannot be saved yet. The user has to press the back button and then click the save button to ensure the data is saved. To remove data of a particular NBC the row has to be selected first, the remove button to be clicked next, followed by back button and finally the clicking of save button will ensure the changes. The adding or removing data in the database has been functioned to be done in multiple steps to ensure that no serious changes are occurred by mistake in haste.

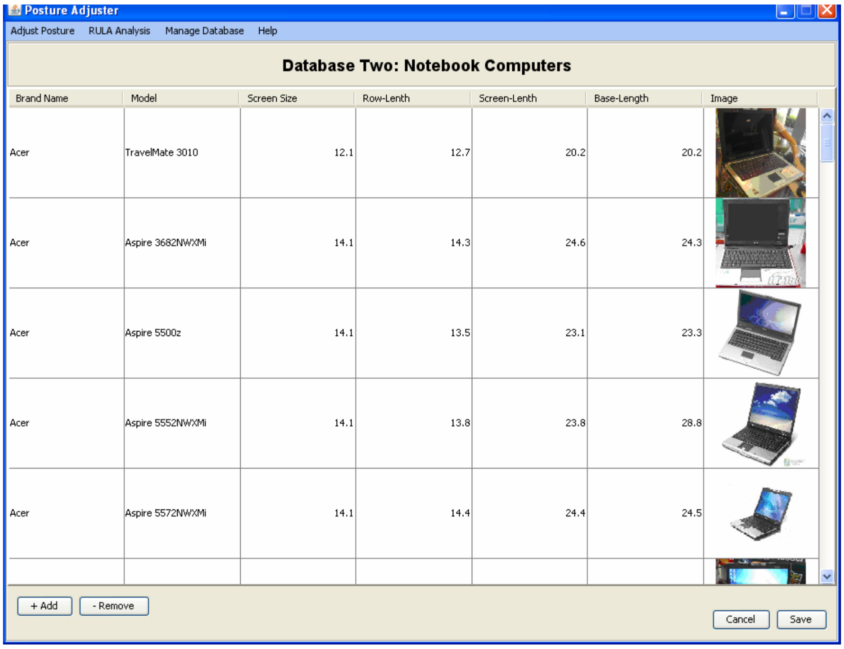


Figure 5.20 NBC Database

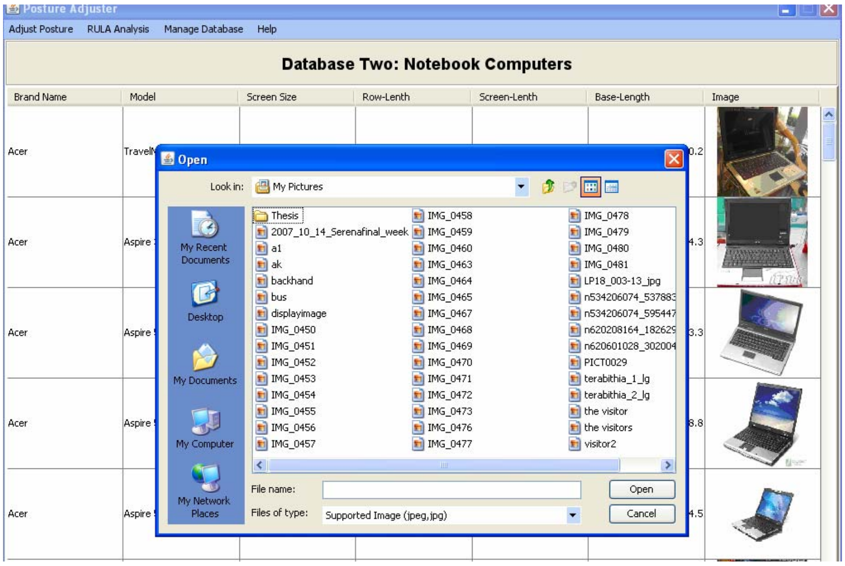


Figure 5.21 Browsing image to Add in the Database

(III). *Management of the Workstation Database*

Managing the work station database is similar to that of anthropometric databases and NBC database. Alike the NBC database, a user does not have to be concerned about any direct effect of the data on the estimation formulas. A data entered in the work station database is solely a unique piece of data that expand the data resource but does not involve or influence any result outcome. The database is separated into table or work surface and chair or seat, as shown in Figures 5.22 and 5.23.

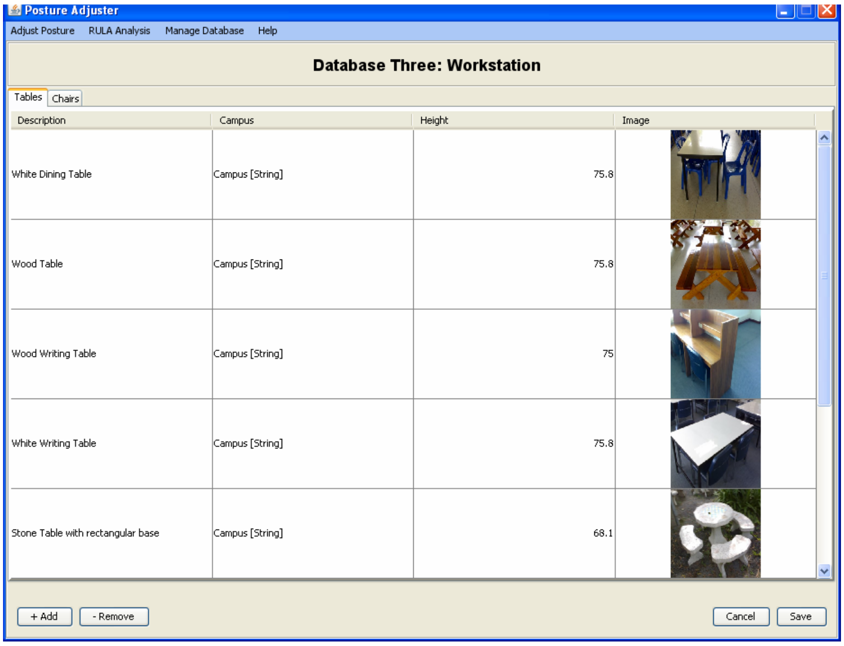


Figure 5.22 Workstation Database - Database of the Work Surface or Table

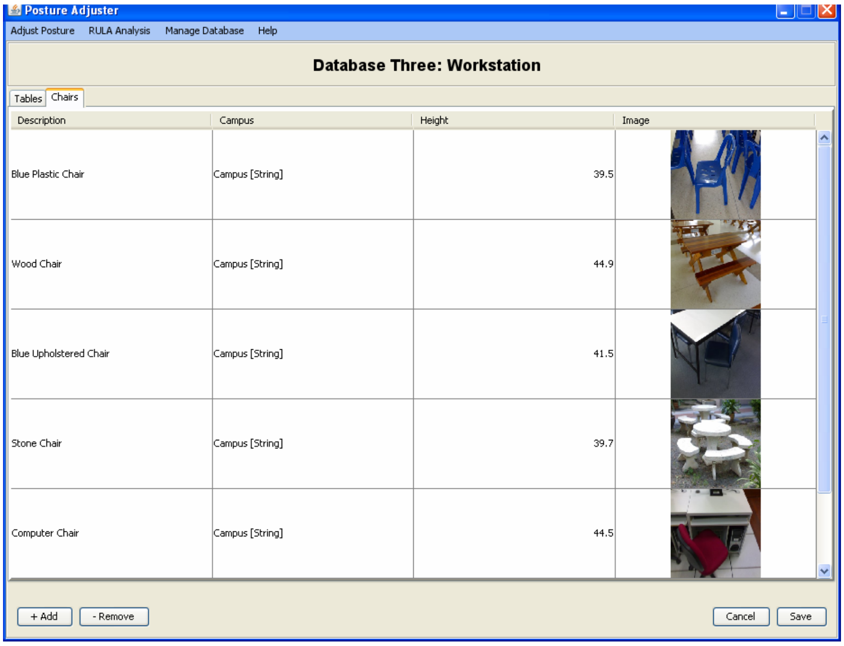


Figure 5.23 Workstation Database -Database of the Seat or Chair

For each table or chair the data to be stored are the description, height and an image. The addition of a new row is done by clicking the add button and then typing the first two fields from keyboard. To add the image field, the user can click on the image field which pops up a browser that can be used to locate and select the image of the work station from any location on the hard disk or external drives. Note that during entering the fields the program already tells the user the type of data to be inserted for that field. In an exception in the data type entry, an error message will appear. The description is of data type string while the height is of float data type and the image is an image file with its designated extension. All three fields have to be filled in here to make a successful addition. The data cannot be saved yet. The user has to press the back button and then click the save button to ensure the data is saved. To remove data of a particular work station the row has to be selected first, the remove button to be clicked next, followed by back button and finally the clicking of save button will ensure the changes. The adding or removing data in the database has been functioned to be done in multiple steps to ensure that no serious changes are occurred by mistake in haste.

CHAPTER 6

VALIDATION TEST

A validation test was conducted to validate the three features of *PostureAdjuster*, the "Evaluate Current Work Posture" feature, the "Determine Ergonomic Work Posture" feature and "Calculate RULA" feature. The test required the subjects to type a text material over a specific time period, once in their preferred posture and the second time with the recommended posture from *PostureAdjuster*. The results of the two trials were compared to validate features of *PostureAdjuster*. Details of the test subjects, equipments, procedure and validation are described in this chapter. The chapter ends with discussions from findings from the test and subjects' subjective opinion which was obtained from questionnaire.

6.1 Subjects

A total of 12 subjects, six males and six females, were tested. The subjects of each gender were selected based on their body heights, such that of the six subjects of each gender, two belonged to the 5th percentile, two belonged to the 50th percentile and two belonged to the 95th percentile population of their genders. The rules followed to determine which subject belonged to which percentile of body height, the most recent Thai anthropometric database (Thai Industrial Standards Institute, 2001) were used. These rules are presented in table 6.1.

Table 6.1 Rules to Determine Body Height percentile of the Subjects

	Male	Female
5th Percentile	Height ≤ 162.4 cm	Height ≤ 150.7 cm
50th Percentile	162.4 cm < Height ≤ 172.0 cm	150.7 cm < Height ≤ 159.3 cm
95th Percentile	Height > 172.0 cm	Height > 159.3 cm

The 12 subjects had five age groups which were 21, 22, 29, 31 and 44 in ascending order. The average age of the subjects was 25.25 years; one subject was of age 44, one subject was of age 31, two subjects were of age 29, two subjects were of age 22 and the rest six subjects were of age 21. The male subjects are denoted as M1, M2, M3, M4, M5 and M6 while the female subjects are denoted as F1, F2, F3, F4, F5 and F6. Table 6.2 presents the male and female subjects in their body height percentile group. The number beside each subject denotes their body height in centimeters.

Table 6.2 Body Height Percentile of the Subjects

Body Height Percentile	Male	Female
5th Percentile	M1 (161 cm), M2 (162 cm)	F1 (149 cm), F2 (150 cm)
50th Percentile	M3 (167 cm), M4 (171 cm)	F3 (154 cm), F4 (159 cm)
95th Percentile	M5 (177 cm), M6 (181 cm)	F5 (165 cm), F6 (172 cm)

6.2 Equipment

6.2.1 Notebook Computers

Notebook computers with different screen-sizes were used, depending on the NBCs owned by the subjects. The NBCs that were tested had screen-sizes of 11 inches, 13 inches, 14 inches and 15 inches, where the majority of the subjects owned a 14 inch screen-size NBC.

6.2.2 Workstations

Two workstations were used, one with an adjustable chair and another with a non-adjustable seat. The work station with an adjustable chair is noted as *WS*1 and the workstation with the non-adjustable seat or wooden bench, is noted as *WS*2. Figure 6.1 presents the two workstations used in the test.

(a) Table (left), Chair (right) of *WS*1 (b) Table (left), Seat (right) of *WS*2

Figure 6.1 Tables and Seats of *WS*1 and *WS*2

*WS*1 consists of a table which is 73.5 cm high and an adjustable chair which has a minimum seat height of 41 cm and a maximum seat height of 50 cm. The adjustable chair can easily be adjusted with a lever on the left side of the chair. *WS*2 consists of a wooden table and a wooden bench which is non adjustable. The table height is 75.8 cm and the bench height is 44.9 cm. The table and the bench are connected at the bottom so the bench cannot be moved away or towards the table. The distance between the edge of the table to the front end of the bench is 10 cm. Each workstation was tested with a 5th percentile, 50th percentile, 95th percentile male and female. Subjects who were assigned to perform test on *WS*1 were M1, M3, M5, F1, F3 and F5 while subjects who were assigned to perform test on *WS*2 were M2, M4, M6, F2, F4 and F6.

6.2.3 Mobile Accessories

Mobile accessories were used to setup the NBC and workstation according to the the recommendations from *PostureAdjuster*. The accessories help to provide base support for NBC, base-tilt angle of NBC, seat support for the seat and to hold the typing document. These mobile accessories are made of wood and are described below.

Notebook Support

The notebook support accessory consists of different layers where the layers can be chosen in different combinations to reach different required heights to provide a support. Figure 6.2 shows the notebook support in its maximum height.

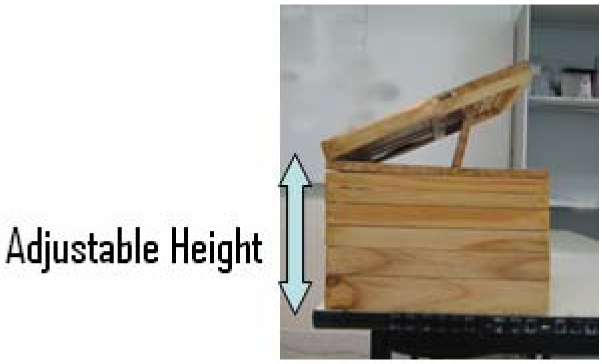


Figure 6.2 Notebook Support at its maximum height

The notebook support's top layer could be slanted to create an angle with the table or work surface, which can provide the tilt angle of the base-unit of the NBC that is required from recommendations of *PostureAdjuster*. This level also consists of the mouse pad which is extended from this layer thus forming the exact angle as the base-unit, shown in figure 6.3. This assures that the mouse and the base-unit are not placed at different angles and thus not causing variation in the wrist angle of the subject while switching between mouse and keyboard.

(a) Extended Mouse Pad (top view) (b) Extended Mouse Pad (side view)

Figure 6.3 Extended Mouse Pad

There are fived different pins under the top layer and it can be adjusted to any of those pins to create an angle. The accessory provides five different angles which are 10º, 15º, 20º, 25º and 30º. Figure 6.4 presents images of the accessory in the five adjustable angles.

(a) 10º angle-the minimum

(b) 15º angle

(b) 20º angle

(b) 25º angle

(e) 30º angle-the maximum

Figure 6.4 Tilt Angles formed by the Notebook Accessory

Document Holder

A wooden accessory is used as a document holder to support the typing material of the test in an upright slanted position. It can be placed anywhere on the work surface and the level of its slant can be changed too. Figure 6.5 presents the document holder.

Figure 6.5 Document Holder

Seat Support

Wooden boards were used as seat support that could be used to increase the height of the body in the seated posture to a recommended height provided by *PostureAdjuster*. The seat support consisted of different layers which could be arranged in different combinations to achieve an intended level of height. Figure 6.6 shows a seat support placed on a seat.

Figure 6.6 Seat Support

6.2.4 Recording Instruments

A Minolta Dimage Xt digital camera was used for recording images of subjects during the test procedure. The maximum resolution is 3.2 megapixels where image sizes can be of maximum size of 2048 X 1536 but during the validity test the resolution was set to be 1600 X 1200 pixels. A Kodak camera tripod was used to mount the camera in order to maintain a constant distance from subjects during the test process.

6.2.5 Data Sheet

Information of each subject was obtained which included subjects name, gender, height, age. Information regarding subjects NBC was also collected which were the average use of NBC per day in hours, screen-size of the subject's NBC in inches, duration the subject has owned that NBC in years. More detailed information about subjects usage habit included subject's preferred way of navigation while using NBC where the choices were touchpad, mouse and trackpoint. Due to the fact that the test was a typing test, subject's typing skills in Microsoft-Word (MS-Word) was collected which included MS-Word experience in terms of years, familiarity of typing tasks in MS-Word such as underlining, bold face, italic face, indenting text, creating table and creating frame. The final information was about subject's typing fluency which was divided in beginner, intermediate and proficient levels.

6.2.6 Questionnaire

A subjective questionnaire was to be filled up by each subject. This questionnaire asked opinions of subjects' perceived discomfort zones and the level of discomfort felt after the typing test. The discomfort zones of interest of the test were the neck, the shoulder, the elbows, the lower back and the wrists. The subjects were provided five choices of scores to measure the discomfort level which ranged from 0 to 4. The scores represented the following levels of discomfort

0 = No discomfort
1 = Little discomfort
2 = Moderate discomfort
3 = Very discomfort
4 = Extreme discomfort (pain)

6.3 Procedure

The test was conducted on one subject at a time. The test on each subject was divided into two trials. In the first trial, the subject was taken to the workstation and had a task of typing, where a typing material was provided. The subject was instructed to adjust his or her NBC in the usual way he or she works and adjust the seat height in case of *WS*1. No assistance was provided during the setup process. Once the subject was ready to type, an instruction to type as accurately as possible was provided. Before the typing, subject's preferred way of NBC orientation namely the tilt angle of the base-unit *AB* and screen angle *BS* and the distance between the subject's body till the front end of the NBC was recorded. The typing task was conducted for 16 minutes. During the task the subject was not allowed to leave the workstation or communicate with outsiders. Photographs were taken every two minutes starting from the beginning. After the end of first trial the subject was allowed to leave. At the end of the trial, the subject was asked to fill in a subjective questionnaire to rate the level of discomfort for certain body parts.

In the second trial, the subject was taken to the same workstation of his or her first trial and had the same task of typing, where the typing material was same as the first trial. The subject's NBC and workstation were adjusted based on the recommended results from *PostureAdjuster*. Tilt angle, screen angle, base support, seat support and a document holder was provided using the mobile accessories mentioned in section 6.2.3. In addition, where footrest was needed, footrest was provided with pile of paper. The subject was next allowed to sit on the adjusted workstation settings and instructed not to make any changes at all. However, the subject could place the document holder at any place on the table that they preferred.

In the second trial, in case of *WS*1 where the adjustable seat had wheels, a table was pushed behind the seat to keep the subject's posture stable. After sitting on the adjusted workstation, once the subject was ready to type, an instruction to type as accurately as possible was provided. The typing task was conducted for 16 minutes. During the task the subject was not allowed to make any change of the workstation, leave the workstation or communicate with outsiders. Photographs were taken every two minutes starting from the beginning. After the end of first trial the subject was allowed to leave. At the end of the trial, the subject was asked to fill in a subjective questionnaire to rate the level of discomfort for certain body parts.

At least five hours of interval was maintained in between the first and the second trial for each subject, in most cases the subjects had the two trials on two separate days. This was done in order to prevent accumulated discomfort from the first trial to the second trial.

6.4 Validity Analysis

PostureAdjuster offers three features which are:

(i) Evaluate Current Work Posture,

(ii) Recommend Ergonomic Work Posture, and
(iii) Calculate RULA Score
The validity of each of these features is described below with test results.

6.4.1 <u>Validation of the "Evaluate Current Work Posture" Feature</u>

Validation of this feature was done by feeding in the data that were collected in the first trial as mentioned in section 6.3. The three data collected are tilt angle of the base-unit *AB*, screen-angle *BS* and the distance between the subject's body till the front end of the NBC. The evaluation is done by following the steps mentioned in section 5.3.1.The validation of each subject is presented in the following tables.

Table 6.3 Evaluation of Subject M1's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	14.79º	
Shoulder Flexion	34.37º	
Elbow Flexion	97.43º	
Wrist Deviation	17.10º (Extension)	
Viewing Distance	66 cm	

Table 6.4 Evaluation of Subject M2's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	14.87º	
Shoulder Flexion	24.68º	
Elbow Flexion	84.65º	
Wrist Deviation	37.29º (flexion)	
Viewing Distance	65.20 cm	

Table 6.5 Evaluation of Subject M3's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	16.41°	
Shoulder Flexion	22.53°	
Elbow Flexion	91.74°	
Wrist Deviation	18.17° (extension)	
Viewing Distance	69.50 cm	

Table 6.6 Evaluation of Subject M4's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	14.55°	
Shoulder Flexion	35.68°	
Elbow Flexion	103.31°	
Wrist Deviation	0°	
Viewing Distance	88.80 cm	

Table 6.7 Evaluation of Subject M5's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	28.10°	
Shoulder Flexion	0°	
Elbow Flexion	87.80°	
Wrist Deviation	4.71° (flexion)	
Viewing Distance	68.30 cm	

Table 6.8 Evaluation of Subject M6's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	20.86º	
Shoulder Flexion	12.12º	
Elbow Flexion	90.58º	
Wrist Deviation	11.12º (extension)	
Viewing Distance	68.70 cm	

Table 6.9 Evaluation of Subject F1's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	10.72º	
Shoulder Flexion	14.60º	
Elbow Flexion	83.22º	
Wrist Deviation	31.96º (flexion)	
Viewing Distance	62.90 cm	

Table 6.10 Evaluation of Subject F2's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	1.16º	
Shoulder Flexion	11.50º	
Elbow Flexion	78.25º	
Wrist Deviation	42.52º (flexion)	
Viewing Distance	55.50 cm	

Table 6.11 Evaluation of Subject F3's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	10.13^{o}	
Shoulder Flexion	0^{o}	
Elbow Flexion	82.39^{o}	
Wrist Deviation	21.65^{o} (flexion)	
Viewing Distance	60.80 cm	

Table 6.12 Evaluation of Subject F4's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	3.49^{o}	
Shoulder Flexion	18.87^{o}	
Elbow Flexion	84.15^{o}	
Wrist Deviation	33.73^{o} (flexion)	
Viewing Distance	61.70 cm	

Table 6.13 Evaluation of Subject F5's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	18.19^{o}	
Shoulder Flexion	1.33^{o}	
Elbow Flexion	82.75^{o}	
Wrist Deviation	18.53^{o} (flexion)	
Viewing Distance	55.60 cm	

Table 6.14 Evaluation of Subject F6's Current Work Posture

Evaluation of Current Work Posture from *PostureAdjuster*		
Viewing Angle/Neck Flexion	22.72º	
Shoulder Flexion	23.37º	
Elbow Flexion	91.03º	
Wrist Deviation	20.53º (extension)	
Viewing Distance	64.60 cm	

Note that, the evaluation process assumes the body in an upright position where the trunk is straight, but in practical, the subjects sit and form a curve at the trunk region and bend the trunk neck and head in a way that it is inclined towards the screen. This results in a discrepancy between the value of the neck angle/viewing angle and the neck posture that is seen in the image. Thought the value seems small, in the image the viewing angle/neck angle can be seen to have a larger value, especially this is very noticeable in case of subjects F2 and F4. The evaluation result from *PostureAdjuster* provides the value of Viewing Angle/Neck Angle which the subject would have if the subject maintained a seated posture with their trunk straight.

6.4.2 Validation of the "Recommend Ergonomic Work Posture" Feature

Validation of this feature was done by feeding in the data that were collected about each subject before any trials as discussed in section 6.2.5. The data required are those that are mentioned section 5.3.2 and recommended ergonomic posture is found by following the steps of section 5.3.2. According to the procedure mentioned in section 6.3, two trials are performed and images are taken during each trial. The two trials before adjustment and after adjustment based on recommendations of *PostureAdjuster*, are compared side by side to provide a visual comparison of improvements in each subject. They are presented in the following tables. The subject's preferred way of sitting in trial 1 is called pre-adjustment which is presented on the left side of each table, while the subject's sitting posture based on the recommendation in trial 2 is called the post-adjustment presented on the right side of each table. Note that the recommendations from *PostureAdjuster* are rounded up or down to apply on the subject based on the adjustment level of the accessories. For example, if the recommendation for a tilt angle is 12º, it is rounded down to 10º because the accessory can provide the angles of 10º, 15º, 20º, 25º and 30º.

Table 6.15 Comparison of Posture of Subject M1 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	13º
Screen Angle *BS*	113º
Body-to-NBC Distance (cm)	25
Base Support (cm)	0
Seat Support (cm)	Max seat height+ 5
Footrest (cm)	13

Table 6.16 Comparison of Posture of Subject M2 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	29º
Screen Angle *BS*	129º
Body-to-NBC Distance (cm)	28
Base Support (cm)	0
Seat Support (cm)	2.5
Footrest (cm)	6.5

Table 6.17 Comparison of Posture of Subject M3 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	19º
Screen Angle *BS*	119º
Body-to-NBC Distance (cm)	22
Base Support (cm)	0
Seat Support (cm)	Increased by 5.5
Footrest (cm)	2.5

Table 6.18 Comparison of Posture of Subject M4 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	14º
Screen Angle *BS*	114º
Body-to-NBC Distance (cm)	25
Base Support (cm)	0
Seat Support (cm)	3.5
Footrest (cm)	1.5

Table 6.19 Comparison of Posture of Subject M5 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	21º
Screen Angle *BS*	121º
Body-to-NBC Distance (cm)	28
Base Support (cm)	8
Seat Support (cm)	Max seat height
Footrest (cm)	0

Table 6.20 Comparison of Posture of Subject M6 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	21º
Screen Angle *BS*	121º
Body-to-NBC Distance (cm)	28
Base Support (cm)	3
Seat Support (cm)	3.5
Footrest (cm)	0

Table 6.21 Comparison of Posture of Subject F1 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	18º
Screen Angle *BS*	117º
Body-to-NBC Distance (cm)	25
Base Support (cm)	0
Seat Support (cm)	Maximum Seat height+1.5
Footrest (cm)	13.5

Table 6.22 Comparison of Posture of Subject F2 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	16º
Screen Angle *BS*	116º
Body-to-NBC Distance (cm)	26
Base Support (cm)	0
Seat Support (cm)	12
Footrest (cm)	21

Table 6.23 Comparison of Posture of Subject F3 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	15º
Screen Angle *BS*	115º
Body-to-NBC Distance (cm)	25
Base Support (cm)	0
Seat Support (cm)	Maximum Seat height+1.5
Footrest (cm)	12

Table 6.24 Comparison of Posture of Subject F4 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	14º
Screen Angle *BS*	114º
Body-to-NBC Distance (cm)	24
Base Support (cm)	0
Seat Support (cm)	10
Footrest (cm)	16

Table 6.25 Comparison of Posture of Subject F5 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	20º
Screen Angle *BS*	121º
Body-to-NBC Distance (cm)	26
Base Support (cm)	0
Seat Support (cm)	Increase Seat Height by 1.5
Footrest (cm)	5

Table 6.26 Comparison of Posture of Subject F6 before and after Adjustments

Pre-Adjustment

Post-Adjustment

Adjustments based on Recommendations from *PostureAdjuster*	
Tilt Angle of Base-Unit *AB*	28º
Screen Angle *BS*	128º
Body-to-NBC Distance (cm)	30
Base Support (cm)	5
Seat Support (cm)	0
Footrest (cm)	1.5

6.4.3 <u>Validation of the "Calculate RULA Score" Feature</u>

To validate *PostureAdjuster*'s RULA score calculation, RULA analysis of each subject was done manually first, using the RULA scoring method in paper which consists of tables and images. For pre-adjustment and post-adjustement, RULA score was performed and recorded. After a 2 days hiatus, RULA analysis was performed on each subject for pre-adjustment and post-adjustment postures using *PostureAdjuster*. The results showed no difference between the manually calculated RULA score and calculated RULA score from *PostureAdjuster*. The results are presented in tables for each subject in the following section.

Table 6.27 RULA Score Comparison of Subject M1

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	2	2	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	2	2
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	2	2	1	1
Leg Score	2	2	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**5**	**5**
Action Level	**Four**	**Four**	**Three**	**Three**

Action Level Interpretation
Three: *Investigation and changes required soon.*
Four: *Investigation and changes required immediately.*

Table 6.28 RULA Score Comparison of Subject M2

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	2	2	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	1	1	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	0	0	0	0
RULA Grand Score	**4**	**4**	**2**	**2**
Action Level	**Two**	**Two**	**One**	**One**

Action Level Interpretation
One: *Posture is acceptable if it is not maintained for long periods of time.*
Two: *Further investigation is needed and changes may be required.*

Table 6.29 RULA Score Comparison of Subject M3

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	2	2	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	2	2	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**4**	**4**
Action Level	**Four**	**Four**	**Two**	**Two**

Action Level Interpretation
Four: *Investigation and changes required immediately.*
Two: *Further investigation is needed and changes may be required.*

Table 6.30 RULA Score Comparison of Subject M4

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	2	2
Trunk Score	2	2	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**4**	**4**
Action Level	**Four**	**Four**	**Two**	**Two**

Action Level Interpretation
Two: *Further investigation is needed and changes may be required.*
Four: *Investigation and changes required immediately*

Table 6.31 RULA Score Comparison of Subject M5

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	1	1	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**4**	**4**
Action Level	**Four**	**Four**	**Two**	**Two**

<u>Action Level Interpretation</u>
Two: *Further investigation is needed and changes may be required.*
Four: *Investigation and changes required immediately*

Table 6.32 RULA Score Comparison of Subject M6


Pre-adjustment


Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	1	1	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**4**	**4**	**3**	**3**
Action Level	**Two**	**Two**	**Two**	**Two**

Action Level Interpretation
Two: *Further investigation is needed and changes may be required.*

Table 6.33 RULA Score Comparison of Subject F1

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	2	2	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	2	2	1	1
Leg Score	1	1	1	1
Muscle use Score	0	0	0	0
Force/Load Score	1	1	1	1
RULA Grand Score	**4**	**4**	**2**	**2**
Action Level	**Two**	**Two**	**One**	**One**

Action Level Interpretation
One: *Posture is acceptable if it is not maintained for long periods of time.*
Two: *Further investigation is needed and changes may be required.*

Table 6.34 RULA Score Comparison of Subject F2


Pre-adjustment


Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	2	2	1	1
Leg Score	2	2	1	1
Muscle use Score	1	1	1	1
Force/Load Score	0	0	0	0
RULA Grand Score	**4**	**4**	**2**	**2**
Action Level	**Two**	**Two**	**One**	**One**

Action Level Interpretation
One: *Posture is acceptable if it is not maintained for long periods of time.*
Two: *Further investigation is needed and changes may be required.*

Table 6.35 RULA Score Comparison of Subject F3

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	2	2	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**4**	**4**
Action Level	**Four**	**Four**	**Two**	**Two**

Action Level Interpretation
Two: *Further investigation is needed and changes may be required.*
Four: *Investigation and changes required immediately*

Table 6.36 RULA Score Comparison of Subject F4

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	2	2
Trunk Score	2	2	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	2	2	2	2
RULA Grand Score	**7**	**7**	**5**	**5**
Action Level	**Four**	**Four**	**Three**	**Three**

Action Level Interpretation
Three: *Investigation and changes required soon.*
Four: *Investigation and changes required immediately.*

Table 6.37 RULA Score Comparison of Subject F5

Pre-adjustment

Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	1	1	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	1	1	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	1	1	1	1
RULA Grand Score	**5**	**5**	**3**	**3**
Action Level	**Three**	**Three**	**Two**	**Two**

Action Level Interpretation
Two: *Further investigation is needed and changes may be required.*
Three: *Investigation and changes required soon.*

Table 6.38 RULA Score Comparison of Subject F6


Pre-adjustment


Post-adjustment

Body Part	Score (Pre-adjustment)		Score (Post-adjustment)	
	Manually Calculated	Calculation by *PostureAdjuster*	Manually Calculated	Calculation by *PostureAdjuster*
Upper Arm Score	2	2	1	1
Lower Arm Score	1	1	1	1
Wrist Score	2	2	1	1
Wrist Twist Score	1	1	1	1
Neck Score	3	3	1	1
Trunk Score	3	3	1	1
Leg Score	1	1	1	1
Muscle use Score	1	1	1	1
Force/Load Score	1	1	1	1
RULA Grand Score	**7**	**7**	**3**	**3**
Action Level	**Four**	**Four**	**Two**	**Two**

Action Level Interpretation
Two: *Further investigation is needed and changes may be required.*
Four: *Investigation and changes required immediately.*

6.5 Findings

The findings of the validation test are listed below for each of the three features of *PostureAdjuster*.

6.5.1 Findings from Validation of the "Evaluate Current Work Posture" Feature

During this validation there was some discrepancy between the result of *PostureAdjuster* and the image taken. Many times the subject in the image has a very bent neck but the result shows the neck to be not bent in that angle. This was due to the reason that during evaluation of a work posture, the algorithm assumes that the subject maintains the trunk and upper body at a straight line. But in reality, a subject always bends or hunches the upper body. This results in this discrepancy with the neck angle and the viewing distance. Other than this, the evaluation of shoulder angle, elbow angle, wrist deviation etc. seems apparent and consistent with the images.

6.5.2 Findings from Validation of the "Recommend Ergonomic Work Posture" Feature

During this validation, subjects' workstation settings were set up with the recommendations from *PostureAdjuster*. Images taken after adjustments have shown significant improvement in the body posture.

Subjective opinions of users based on questionnaire showed that all subjects reported less discomfort around neck and shoulder region after working in the recommended posture. Majority of the time the subjects felt more comfortable in the recommended posture around elbow, wrists and lower back, except there were two complaints of increased lower back discomfort.

6.5.3 Findings from Validation of the "Calculate RULA Score" Feature

The manually calculated RULA score and the RULA score calculated using *PostureAdjuster* had no difference at all.

6.5.4 Statistical Significance of Users' Perceived Discomforts

The scores collected from questionnaires described in 6.2.6, were used for statistical analysis. Table 6.39 presents the data which consists of subjects and their subjective opinion scores of a certain body part for the two trials. The first trial is the pre-adjustment situation which is stated in the table as 'Before' and the second trial is the post-adjustment situation based on recommendations, which is stated as 'After' in the table.

Table 6.39 Summary of Perceived Discomfort both Before and After Posture Adjustment

Subject	Neck		Shoulder		Elbow		Lower Back		Wrists/Hands	
	Before	After	Before	After	Before	After	Before	After	Before	After
M1	2	1	2	1	0	0	3	2	0	0
M2	1	0	0	0	0	0	0	0	0	1
M3	1	0	2	0	0	0	0	1	1	0
M4	2	1	1	0	0	1	3	1	0	2
M5	1	0	2	1	2	0	3	1	1	0
M6	3	0	1	1	0	1	0	0	2	0
F1	0	0	2	0	0	0	0	0	0	0
F2	2	0	3	2	0	0	1	0	1	0
F3	2	0	3	0	4	0	0	3	1	0
F4	2	0	1	0	0	0	3	2	1	0
F5	2	0	2	1	1	1	3	3	1	1
F6	0	0	0	0	1	1	1	0	0	0

These scores were used to perform the paired t-test to check if the use of *PostureAdjuster* as an ergonomic intervention tool had significantly improvised the body parts. A significance level of 0.05 was used for the analysis. The results are presented below.

Neck

The P value for neck was 0.0003 which states, that the difference between the discomforts of the users' subjective opinion is extremely statistically significant. So the ergonomic intervention has been an improvement for the neck.

Shoulder

The P value for shoulder was 0.005 which states, that the difference between the discomforts of the users' subjective opinion is statistically very significant. So the ergonomic intervention has been an improvement for the shoulder.

Elbow

The P value for elbow was 0.4175 which states, that the difference between the discomforts of the users' subjective opinion is statistically not significant.

Low Back

The P value for low back was 0.4175 which states, that the difference between the discomforts of the users' subjective opinion is statistically not significant.

Wrists/Hands

The P value for wrist was 0.0891 which states, that the difference between the discomforts of the users' subjective opinion is statistically not significant.

To summarize, the statistical analysis showed significant improvements of body discomforts after obtaining the recommended posture of *PostureAdjuster*.

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 General Conclusion

It is very important to maintain an ergonomic body posture during operating NBC. Following certain ergonomic guidelines, this research provides with two adjustment algorithms, one with no workstation constraints and another with workstation constraints. The decision support system, *PostureAdjuster*, uses these algorithms to provide quantitative recommendations for adjusting body and NBC on any workstation. The validity of the decision support system has shown significant improvements in body postures of subjects. Subjects' opinions also showed that they perceived less discomfort after maintaining recommended postures from the decision support system.

Due to the hinge design which attaches the base-unit of an NBC with its screen-unit, a perfect ergonomic posture is unattainable for NBC computers which results into various MSD and discomfort especially around the neck, shoulder and wrist regions. The algorithms provided in this research follows ergonomic guidelines to maintain a proximate posture to the perfect ergonomic posture that is obtained while using a DPC. The two algorithms deal with two situations, one with constrained workstation and another with no constraints. The decision support system-*PostureAdjuster*, assists users to easily use the algorithms and find out recommendations that are easy to follow in order to maintain the proximate work posture. In addition, the *PostureAdjuster* also helps to evaluate a work posture that a user might normally adopt by matching neck, shoulder, elbow, wrist angles and viewing distance against their respective values according to ergonomic guidelines.

The recommendations provided can be directly applied to all genders, any age group and any percentile of the population. The recommendations from *PostureAdjuster* provides only the necessary simple outputs that are easy for the users to follow which includes, seat height, work surface height, body-to-NBC distance, tilt angle of the base-unit and screen angle; additionally there might be recommendations about seat support, base support and footrest. These outputs were selected to be shown to users because it is impossible for a user to measure the neck angle, shoulder angle, elbow angle, wrist angle and maintain them because all of them require a reference point or axis and a user himself cannot see a side view of his posture to control the angles. But with the provided recommendations it is guaranteed that these angles will be maintained.

Although the anthropometric data that are used in the algorithms are estimated from the "bare-foot" body height, a "bare-foot" condition is however not imposed on the NBC users when using either algorithm to obtain adjustment recommendations. Readers should be reminded that the recommended seat height (or seat support) from the algorithms serves as an upper bound of the seat height at which the NBC user can sit comfortably without their feet dangling. In case, NBC user wears shoes, the shoe heal height raises their knee-joint and upper legs up above the seat, providing additional clearance to further prevent thigh compression. This raised height of the knee join does not affect the rest of the body reference points. Thus, wearing shoes during NBC operation does not adversely affect the adjustment recommendations.

The validation tests were done on two workstations. On each workstation, one subject of 5^{th}, 50^{th} and 95^{th} percentile was tested for both the genders. Image results of the validation test gives a visual comparison of postures, before and after adjustments based on recommendations of *PostureAdjuster*. All the results have shown improvements in the body posture of the users with the recommendations from *PostureAdjuster*. User's subjective opinions also demonstrated that every user perceived less discomfort after maintaining the recommended posture for a 16 minute typing task. RULA analysis performed on pre-adjustment posture and post-adjustment postures also show improvements and support the fact that the postures obtained by following recommendations of *PostureAdjuster* makes the body posture less injury prone.

The neck and shoulder positions were compromised from the perfect ergonomic seated posture; guidelines to be considered were to keep neck and shoulder in the least risky posture with no wrist deviation. The trade-off was elbow discomfort, which was possibly caused due to the fact that the elbow was not supported and was not left to hang naturally along the side of the trunk. This was caused because of the elevated upper arms from the perfect ergonomic posture.

The paired t-tests for neck and shoulders showed that users perceived significant decrease in discomfort with the use of *PostureAdjuster*. By maintaining the correct eye-level height of the screen and the correct keyboard height provided by *PostureAdjuster* naturally help the user to maintain proper angles on the neck and shoulders. This contributed in this significant improvement. No significant difference was found between perceived discomforts around elbow and lower back region although the images show visual posture improvements around these regions. This might be due to the fact that the 16 minute test was too short for the user to observe discomforts around these regions. On the wrists/hands, significant difference was not found between perceived discomforts around although the images show visual posture improvements and very little wrist deviation. Only two of the subjects had a typing level of professional standard while the others were mostly intermediate level typists who lacked the intensity level of typing .

The validation shows success of *PostureAdjuster*. In future NBC designs might change with implementation of new technologies. For example the screen unit of NBC might have the ability to be extended from the base-unit. Various kinds of changes in NBC design are possible. Even though changes may occur in NBC design, *PostureAdjuster* could still be useful to determine the height and placement of workstation.

7.2 Contribution of This Research Work

The first and foremost output of this research is the decision support system-*PostureAdjuster*, which is equipped with small databases about popular NBCs in the market and it is a standalone program, not web-based, so users or ergonomic practitioners can use it anywhere to obtain evaluation, recommendation and even RULA analysis. It is easy to use and freely distributable due to the fact it is built in Java.

The adjustment algorithms developed are the first of this kind. The algorithm can locate body coordinates and NBC coordinates thus the body posture and NBC posture at any seated height. This can be a great direction for future researches involving body posture algorithms with the side view. So it can be used for various purposes such as to evaluate body posture of people driving vehicles, body posture of pilots using display terminals, body posture of sailors navigating ships.

The adjustment algorithm can also be enhanced by adding more steps and more inputs to find out how people would sit non-ergonomically at a leisurely position. The DSS could be enhanced to store more data where adjustable and non-adjustable chairs can be stored and user does not have to measure the adjustment level of the chairs.

7.3 Future Research

This research work has contributed by providing recommendations of improvement of posture, analytical algorithms and a decision support system. The research work could be carried on to do further research in the following areas in future which are described below.

7.3.1 Improvement of "Evaluation of Current Work Posture" Option

Currently, the feature "Evaluation of Current Work Posture" provides some results which are inconsistent with the images of subjects in that work posture. While evaluating a work posture, the algorithm assumes that the subject is seated with an upright position with the trunk straight in the ergonomic position. But in reality, it is seen that subjects often tend to hunch and sit in a position that allows the back to form a curve. This results in the inconsistency of the neck angle/viewing angle if matched with the image of the subject. For future research, the algorithm should be enhanced to evaluate the bending nature or seating posture of a subject.

7.3.2 Technical Enhancement of "Calculate RULA Score" Option

Currently, in the "Calculate RULA Score" feature, the user has to load some image and then manually select between the options of body part postures. Only the calculation of the score is done automatically, but all selection process has to be done manually. In future, the decision support system could be enhanced to have a module inside that can automatically calculate RULA score by only uploading an image, so that the user does not have to make selection for each body part posture. This would result in complete automatic computation of RULA score from an image.

7.3.3 Development of a web-based version of *PostureAdjuster*

Another version of *PostureAdjuster* could be developed as a web-based system. The benefits of a web-based version would be

- users not owning the program can use internet for using it from anywhere, anytime especially travelers can benefit from it
- data of new models of notebook computers and workstations that are available to the market could be added by users from around the world so the NBC database and the workstation database could be expanded easily (note that, anthropometric data would not be allowed to be added by users as mentioned in section)

However, there are several drawbacks which are

- it cannot be used without the presence of internet
- *PostureAdjuster* involves calculations and as a web-based version its performance could be inconsistent because it is dependent on internet speed
- internet service providers limitations can make the input screens of *PostureAdjuster* to appear differently in different browsers or locations, which would make it look not as a standardized system
- if *PostureAdjuster* is commercialized in future, the web-based systems are not suitable, instead a standalone program is easy to be commercialized. Also considering the life of a software use, web-based systems turn out to be more expensive over time of use while in a standalone program, the cost is paid only once.

7.3.4 Addition of standing work posture in *PostureAdjuster*

Besides using NBC in a seated posture, there are also cases when people use them while standing. The standing posture could be considered and added as a new feature of *PostureAdjuster*. In that case, only the work surface height should be considered and the seat-height should be omitted. A recommendation for this research would be to start by using lengths of upper leg and lower leg and add together to locate the hip-joint (H) at a standing position and then using the same formulas to locate the coordinates of rest of the body reference-points and make necessary parameter and input adjustments in the current algorithms.

REFERENCES

Harris, C. and Straker, L. (2000), Survey of physical ergonomics issues associated with school children's use of laptop computers, *International Journal of Industrial Ergonomics*, 26: 337-346.

Horikawa, M. (2001), Effect of visual display terminal height on the trapezius muscle hardness: quantitative evaluation by a newly developed muscle hardness meter, *Applied Ergonomics*, 32: 473-478.

Human Factors Society (1988), *American National Standard for Human Factors Engineering of Visual Display Terminal Workstations* (ANSI/HFS 100-1988), Santa Monica, USA.

Kadefors, R. and Laubli, T. (2002), Muscular disorders in computer users: introduction, *International Journal of Industrial Ergonomics*, 30: 203-210.

Lueder, R. (1996), A proposed RULA for computer users, *Proceedings of the Ergonomics Summer Workshop*, San Francisco, USA.

McAtamney, L. and Corlett, E.N. (1993), RULA: a survey method for the investigation of work-related upper limb disorders, *Applied Ergonomics*, 24(2): 91-99.

Moffet, H., Hagberg, M., Hansson-Risberg, E., and Kalrqvist, L. (2002), Influence of laptop computer design and working position on physical exposure variables, *Clinical Biomechanics*, 17(5): 368-375.

Rurkhamet, B. and Nanthavanij, S. (2004a), Analytical design methodology for recommending VDT workstation settings and computer accessories layout, *Industrial Engineering and Management Systems*, 3(2): 149-159.

Rurkhamet, B. and Nanthavanij, S. (2004b), Analytic and rule-based decision support tool for VDT workstation adjustment and computer accessories arrangement, *Journal of Human Ergology*, 33: 1-17.

Saito, S., Miyao, M., Konto, T., Sakakibara, H., and Toyoshima, H. (1997), Ergonomic evaluation of working posture of VDT operation using personal computer with flat panel display, *Industrial Health*, 35(2): 264-270.

Sommerick, C.M., Starr, H., Smith, C.A., and Shivers, C. (2002), Effects of notebook computer configuration and task on user biomechanics, productivity, and comfort, *International Journal of Industrial Ergonomics*, 30: 7-31.

Stammerjohn, L.W., Smith, M.J., and Cohen, B.F.G. (1981), Evaluation of workstation design factors in VDT operations, *Human Factors*, 23: 401-412.

Straker, L., Jones, K.J., and Miler, J. (1997a), A comparison of the postures assumed when using laptop computers and desktop computers, *Applied Ergonomics*, 28: 263-268.

Straker, L., Pollock, C.M., and Mangharam, J.E. (1997b), The effect of shoulder posture on performance, discomfort and muscle fatigue whilst working on a visual display unit, *International Journal of Industrial Ergonomics*, 20: 1-10.

Straker, L., and Mekhora, K. (2000), An evaluation of visual display unit placement by electromyography, posture, discomfort and preference, *International Journal of Industrial Ergonomics*, 26: 389-398.

Straker, L., Pollock, C.M., and Limerick, R.B. (2006), Towards evidence-based guidelines for wise use of computers by children, *International Journal of Industrial Ergonomics*, 36: 1045-1053.

Szeto, G.P. and Lee, R. (2002), An ergonomic evaluation of desktop, notebook and subnotebook computers, *Archives of Physical Medicine and Rehabilitation*, 83(4): 527-532.

Thai Industrial Standards Institute (2001), *Report of the Survey and Research on the*

Anthropometric Data of Thai Population, Ministry of Industry, Thailand.

Villanueva M.B., Sotoyama M., Jonai H., Takeuchi Y., Saito S.(1996), Adjustments of posture and viewing parameters of the eye to changes in the screen height of the visual display terminal, *Ergonomics*, 39(7):933-945.