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Analytical Algorithms for Ergonomic Seated Posture When Working with Notebook Computers

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Abstract. This paper discusses 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).

Keywords: Notebook Computer, Adjustment Algorithms, Seated Posture, Workstation, Visual Display Terminal (VDT)

1. INTRODUCTION

It is known that prolonged visual display terminal (VDT) operation can lead to musculoskeletal disorders (MSDs) and cumulative trauma disorders (CTDs) such as low back pain, carpal tunnel syndrome (CTS), stiff shoulders, and sore neck. The problems are more intensified if work posture is awkward, e.g., bent neck, bent wrists, or flexed/extended forearms. Numerous research studies were conducted to give recommendations about VDT operation and seated posture, resulting in the ANSI/HFS 100-1988 Standard (The Human Factors Society, 1988). Kadefors and Laubli (2002) presented chronographic observations of work-related disorders in accounting, administration and communication works, Morse machine works, punch-card works, and leading up to computer works in the eighties until the current decade. They also discussed a European project called PROCID (Prevention of Muscular Disorders in Operation of Computer Input Devices), initiated in 1998, which considered both physical and mental stresses during computer uses. Nevertheless, PROCID only provided recommendations to complement other standards such as ANSI/HFS 100-1988. Straker *et al.* (2006) stated that the VDT used in offices involves both computer- and paper-based information technology work, but there were no studies about desk evaluation for both types of task.

While there are several recommendations and guidelines for VDT operation, they are descriptive in nature and rather difficult to implement. Rurkhamet and Nantha-vanij (2004a) developed an analytical design method for computing workstation settings and positioning computer accessories so as to help VDT users sit with a correct posture. Later, Rurkhamet and Nanthavanij (2004b) developed EQ-DeX, a rule-based decision support system, based on their analytical algorithm. The EQ-DeX provides quantitative adjustment recommendations and displays line figures to illustrate the resulting workstation settings and computer accessories layout.

During the recent years, the use of notebook computers (NBCs) has quickly become very popular among computer users due to their light weight, small size, ease of portability, and battery power option. Unlike conventional VDT workstations, the NBC workstation is difficult to define since NBCs can be used under various work settings. Therefore, it is reasonable to suspect that NBC

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users' work postures are likely to be more awkward than those of desktop computer users'. Consequently, their body discomforts should also be more severe. Straker *et al.* (1997a) presented a comparison of body postures during desktop computer and NBC operations. The results revealed that in terms of postural constraints and discomforts, desktop computer users felt better even after 20 minutes of computer use. Horikawa (2001) did a quantitative examination on the relation between screen height and trapezius muscle hardness on subjects using desktop computers and NBCs. The results showed that with 15 minutes of data entry work on NBCs, the hardness of trapezius muscle is increased.

Because of its hinge design, the heights of NBC base and screen units cannot be adjusted independently. This design could lead to a body posture with excessive stresses at the neck and shoulder regions. Szeto and Lee (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 increases the load on the spine which influences the subjects 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 discomforts since the viewing distances were shorter than the recommended viewing distances for desktop computer operation. Straker *et al.* (1997b) also studied the effect of shoulder posture on work performance, discomfort, and fatigue with respect to shoulder flexions of 0° and 30°. The results indicated that fatigue around the anterior deltoid is significantly affected by the 30° shoulder posture.

Sommerich *et al.* (2002) conducted a detailed study to evaluate the effects of NBC on body posture when being operated in a stand-alone condition and with inexpensive ordinary peripheral input devices such as external keyboard, mouse, and numeric pads. They investigated how head and neck angles, trunk angle and thoracic bend, shoulder and elbow angles, and wrist posture of NBC users were influenced. The results showed that in the stand-alone condition, the body postures were more deviated from the neutral positions. They concluded that the use of external peripheral devices (such as keyboard) can reduce stress on the neck.

The results from research studies on NBC operation led to the "do's" and "don'ts" guidelines. However, to our knowledge, no quantitative adjustment recommendations have been given. In this study, we develop two analytical algorithms to recommend how to practically adjust the NBC and the workstation so that NBC users can sit with the correct posture. They are: (1) algorithm without workstation constraints, and (2) algorithm with workstation constraints.

The paper is organized as follows. Firstly, we introduce the recommended work posture for NBC operation. Next, we describe the required input data. Then, we explain the two algorithms in detail. Finally, we present a validation of the adjustment algorithms using two subjects, one male and one female. We compare their seated postures both before and after implementing the adjustment recommendations. An analysis technique called Rapid Upper Limb Assessment (RULA) initially developed by McAtamney and Corlett (1993) and later revised by Lueder (1996) is used to evaluate the pre-adjustment and post-adjustment work.

2. RECOMMENDED POSTURE

As recommended in the ANSI/HFS 100-1988 Standard, the VDT user should sit with the back at an upright (or slightly reclined) position; the upper arms should hang naturally along the side of the trunk; the elbows are fixed at 90° while keeping the lower arms horizontal; the lower arms and hands should form a straight line; the lower legs should form a right angle (90°) with the upper legs; both feet should rest comfortably on the floor. The monitor should be placed such that the user can view the screen comfortably without bending his/her neck. 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 utilized to provide practical recommendations for adjusting the VDT workstation and arranging computer accessories on the work surface (Rurkhamet and Nanthavanij, 2004b).

To make it portable, the NBC has its base and screen units connected by hinges. This design prohibits the heights of the base (or keyboard) and screen (or monitor) from being adjusted independently; thus, imposing conflicting constraints on the body posture. More specifically, 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, 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.

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

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.

2.2 Shoulder

Straker *et al* (1997b) showed that over a 20-minute work period, 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°.

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 shorter 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.

From the general recommendations given in the ANSI/HFS 100-1988 Standard and the above recommendations, it can be concluded that the NBC user should sit with the back at an upright (or slightly reclined) position; neck flexion should not be more than 10°; shoulder flexion should not be more than 20°; elbow flexion should be about 90°; the lower arms and hands should form a straight line; the lower legs should form the right angle (90°) with the upper legs; both feet should rest comfortably on the floor. Additionally, the viewing distance should be between 38 and 62 cm. Figure 1 shows a sketch of the recommended work posture during NBC operation.

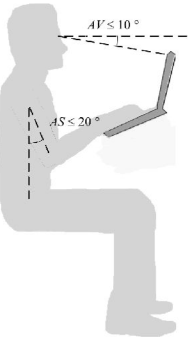

Figure 1. Recommended work posture during NBC operation (*AS* = shoulder flexion angle and *AV* = viewing angle).

3. REQUIRED DATA

3.1 Dimensions of Body Parts

The following anthropometric data are required to generate the adjustment recommendations: (1) body height *BH*, (2) eye height (sitting) *IH*, (3) shoulder height (sitting) *SH*, (4) length of upper arm *UA*, (5) length of lower arm *LA*, (6) length of hand *HA*, (7) popliteal height (sitting) *HH*, (8) length of upper leg *UL*, and (9) length of lower leg *LL*. Anthropometric data of the Thai population can be found in Thai Industrial Standards Institute (2001). For each gender, the data are divided into four age groups, namely, 17~19, 20~29, 30-39, and 40-49 years of age. Table 1 shows selected anthropometric data expressed as average proportions of body height for the 5th, 50th, and 95th percentiles.

From Table 1, it is seen that there are six sets of formulas to estimate the required anthropometric data

Table 1. Selected anthropometric data of Thai population (as proportions of body height)

	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

Note: P5, P50, and P95 represent the 5th, 50th, and 95th percentiles, respectively.

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:
$BH \leq 150.7$ - use the formula set for P5
$150.7 < BH \leq 159.3$ - 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.

3.2 Body Reference Points

In order to give quantitative adjustment recommendations, certain body reference points must be defined. 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*. It is further 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*.

By mapping the body on the sagittal (*x*, *y*) plane, we can determine the (*x*, *y*) coordinates of the above body reference points. Letting

AB = tilt angle of NBC base unit,
AE = elbow angle, measured between the upper and lower arms,
AS = shoulder flexion angle, measured between the trunk and upper arm,
AV = viewing angle, measured between the horizontal line and the normal line of sight (at the screen top),
AW = wrist deviation angle, measured between the lower arm and hand,
BS = screen angle, measured between the NBC base and screen units, and
ES = incidence angle, measured between the normal line of sight and the screen surface,

and assuming that the reference vertical line is the line that passes the mid points of the head and trunk, we obtain the following coordinates.

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*): $H_x = 0$
$H_y = K_y$

Figure 2 shows all angle measurements of the body and NBC as defined earlier. Figure 3 shows the body reference points and body segments that are required for the algorithms.

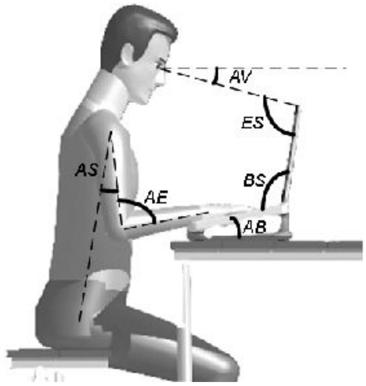

Figure 2. Required angle measurements of the body and NBC

3.3 NBC Reference Points

Similarly, it is necessary to know some physical dimensions of the NBC in order to define the coordinates of its reference points. Firstly, three physical dimensions must be determined (either from direct measurement or estimation). They are: (1) distance between the front edge of the base unit and the keyboard's home row *RL*, (2) distance between the front and rear edges of the base unit *BL*, and (3) distance between the top and bottom edges of the screen unit *SL*.

Next, selected reference points of the 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 top edge of the screen unit *T*. Note that the rear edge of the base unit and the bottom edge of the screen unit are the same reference point.

The coordinates of the NBC reference points are as shown below. For further details, see Figure 4.

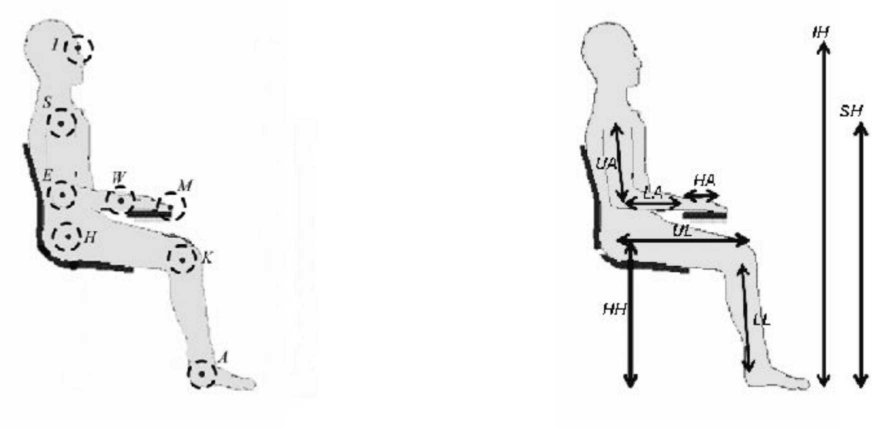

Figure 3. Body reference points (left) and segments (right)

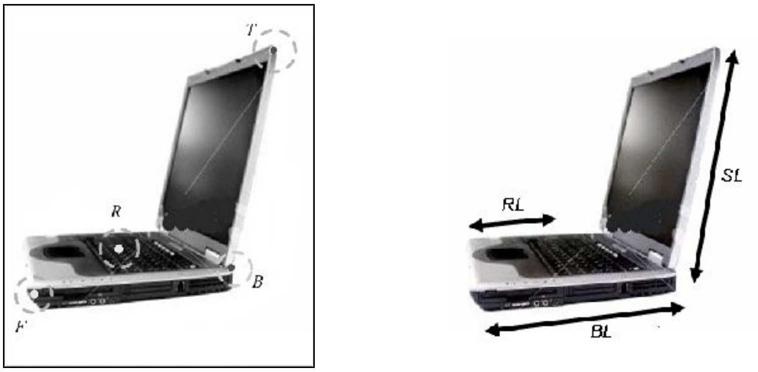

Figure 4. NBC reference points (left) and dimensions (right)

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

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

4. ADJUSTMENT ALGORITHMS

Two adjustment algorithms are proposed. 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 Section 2, and provides the coordinates of all reference points as the outputs. This algorithm helps to determine the adjustment recommendations to obtain the *ideal* seated posture when working with the NBC.

In reality, however, most NBC users normally sit on a chair and place their NBC on a table during their NBC operation. Thus, two workstation constraints, namely, seat and work surface heights, are necessary to simulate the real work situation of NBC users. More specifically, they are pre-requisites for *realistic* adjustment recommendations. Briefly, the second algorithm which considers both workstation constraints 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.

Shown below are additional formulas which are used in the algorithms.

1. When points P and Q are given, a straight-line distance PQ between them can be determined from

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

2. 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

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

3. 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

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

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

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

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

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

4.1 Algorithm without Workstation Constraints

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:

A1. Given *BH*, determine *IH*, *SH*, *UA*, *LA*, *HA*, *HH*, *UL*, and *LL*.
A2. 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.
A3. Determine R_x, R_y, F_x, F_y, B_x, B_y, T_x, and T_y.
A4. Determine *ES*.
A5. Check if $ES = 90°$:

- If $ES = 90°$, proceed to Step A6.
- If $ES < 90°$, decrease *BS* by 1°. Then, check the new *BS*.
  - If $BS > 90°$, determine T_x, T_y, and *ES*. Repeat Step A5.
  - If $BS = 90°$, determine T_x, T_y, and *ES*. If $ES = 90°$, proceed to Step A6. Otherwise, stop (infeasible posture).
- If $ES > 90°$, increase *BS* by 1°.
  - If $BS < 180°$, determine T_x, T_y, and *ES*. Repeat Step A5.
  - If $BS = 180°$, determine T_x, T_y, and *ES*. If $ES = 90°$, proceed to Step A6. Otherwise, stop (infeasible posture).

A6. Determine *AV*.
A7. Check *AV*.

- If $AV \leq 10°$, determine the viewing distance *VD*.
  - If $38 \leq VD \leq 62$ cm, go to Step A16.
  - Otherwise, proceed to Step A8.
- If $AV > 10°$, proceed to Step A8.

A8. Set $VD = 62$ cm and $AV = 10°$. Then, determine T_x and T_y.
A9. Set $ES = 90°$. Then, determine B_x and B_y.
A10. Find *E* as an intersection point of two circles where

- Circle 1 has its center at point *P* and its radius of *UA* from Step A1.
- Circle 2 has its center at point *Q* and radius equal to the distance from *B* to *E*.

A11. Determine *AB*.
A12. Determine W_x, W_y, M_x, M_y, R_x, R_y, F_x, and F_y.
A13. Determine *AS* (from *H*, *S*, and *E*).
A14. Check *AS*.

- If $AS \leq 20°$, go to Step A16.
- If $AS > 20°$, proceed to Step A15.

A15. Decrease *VD* by 1 cm. Then, check the new *VD*.

- If $VD > 38$ cm, determine T_x and T_y. Repeat Steps A9 - A14.
- Otherwise, stop (infeasible posture).

A16. The compromised body posture, recommended seat height, recommended work surface height, tilt angle of the base unit, and screen angle are obtained.

Figure 5 shows a flow chart of the algorithm without workstation constraints.

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 be recommended.

Initially, the first algorithm (in Section 4.1) is used to determine the adjustment recommendations without workstation constraints. 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 rec-

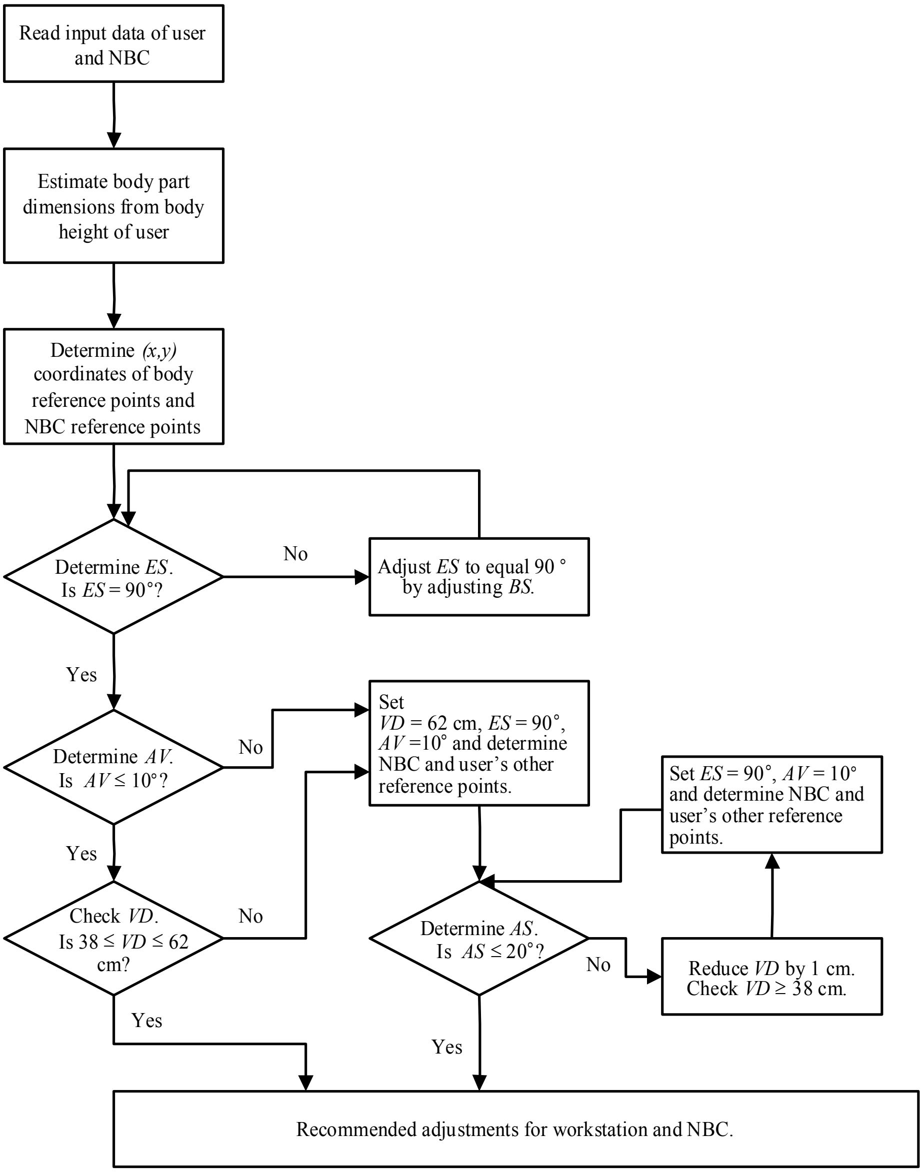

Figure 5. Flow chart of the algorithm without workstation constraints

ommendations that satisfy the workstation constraints.

Adjustment Procedure:
(Steps B1~B15 are identical to Steps A1~A15 in Section 4.1).

B16. 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.

B17. For condition = 1, no adjustments are required. Go to Step B26.

B18. For condition = 2:
- Add base support = $HH - AWH$.
- Go to Step B26.

B19. For condition = 3:
- Add seat support = $AWH - HH$.
- Add footrest = $AWH - HH$.
- Go to Step B26.

B20. For condition = 4:
- Add seat support = $HH - AHH$.
- Go to Step B26.

B21. For condition = 5:
- Add seat support = $HH - AHH$.

- Add base support = $F_y - AWH$.
- Go to Step B26.

B22. For condition = 6:
- Add seat support = $(HH - AHH) + (AWH - F_y)$.
- Add footrest = $AWH - F_y$.
- Go to Step B26.

B23. For condition = 7:
- Add footrest = $AHH - HH$.
- Add base support = $AHH - HH$.

B24. For condition = 8:
- Add footrest = $AHH - HH$.
- Add base support = $(AHH - HH) + (F_y - AWH)$.
- Go to Step B26.

B25. For condition = 9:
- Add footrest = $AHH - HH$.
- Determine the revised F_y.
  - If the revised $F_y = AWH$, go to Step B26.
  - 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 Step B26.

B26. 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.

B27. The compromised body posture, recommended seat height, recommended work surface height, tilt angle of the base unit, screen angle, recommended heights of footrest, seat support, and base support are obtained.

Figure 6 shows a flow chart of the algorithm with workstation constraints.

5. VALIDATION

The adjustment algorithms described in Section 4 are coded using the MATLAB program. They are tested on two subjects, one male and one female. The validation procedure can be described as follows.

The subject is given a notebook computer with its screen size of 11.1 inches. Then, he/she is requested to set it at a workstation which consists of a chair with its seat height of 38 cm and a table with its work surface height of 75 cm. The subject will arrange the position of the NBC at the workstation without any assistance.

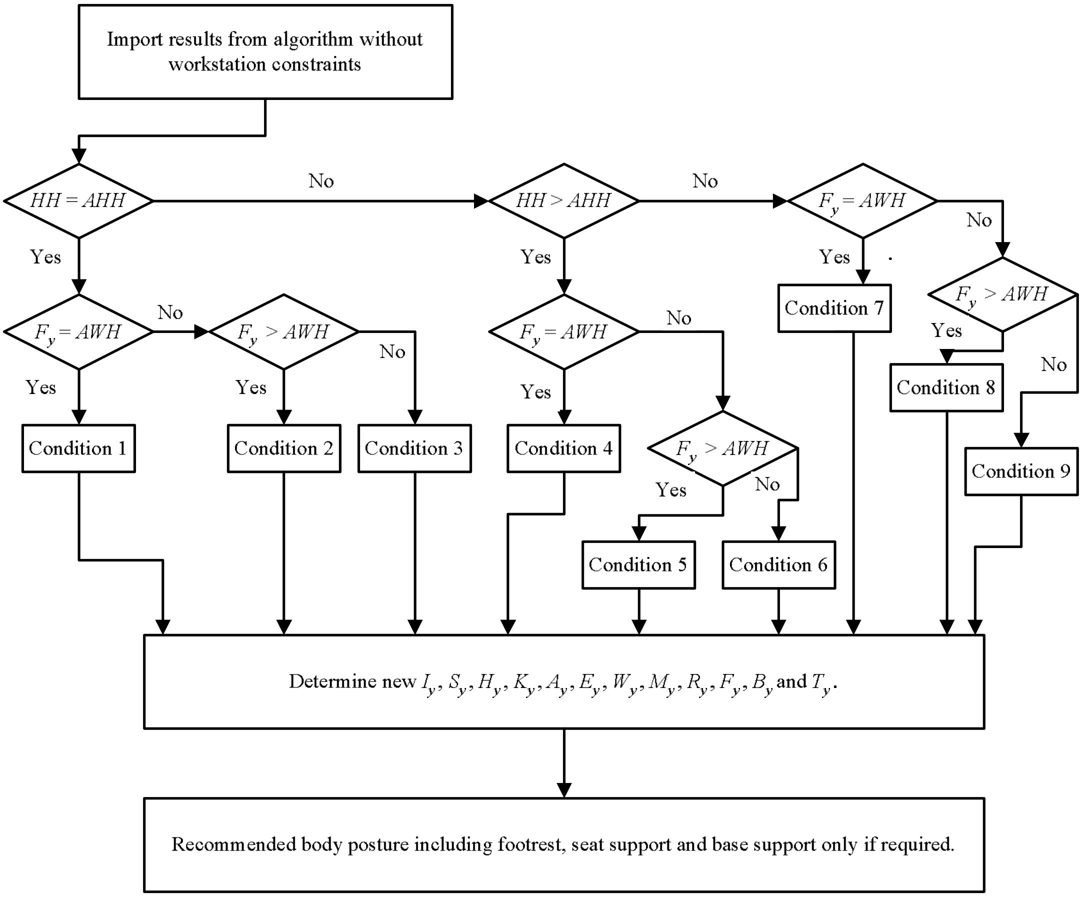

Figure 6. Flow chart of the algorithm with workstation constraints

While performing NBC operation, a digital image of the subject's body posture is recorded and the RULA analysis is applied to analyze the recorded posture. From the subject's body height, gender, physical dimensions of the NBC, actual seat height, and actual work surface height, the algorithms determine necessary adjustments for the NBC and the workstation. After implementing the adjustments, the subject is asked to operate the NBC again. Another digital image of the subject's body posture is recorded. The RULA analysis is again applied to analyze the new work posture.

Table 2 summarizes the adjustment recommendations for the two subjects. It can be seen that although both subjects sit at the same workstation and use the same notebook computer, their required NBC and workstation adjustments are different. This is mainly due to the differences in their anthropometric data. Figures 7 and 8 show the comparisons of body postures of both subjects, respectively. In each figure, readers can see the improvement of work posture by comparing the first image (recorded before implementing the recommendations) to the second image (recorded after the NBC and the workstation have been adjusted).

From Figure 7, it is seen that the male subject (*BH* = 178 cm) has to sit on a low chair (*AHH* = 38 cm). Due to his tall stature, it is not surprising that the subject has to bend his neck excessively in order to view the screen. It is also observed that the work surface is low (*AWH* = 75 cm) and the subject positions the NBC too close to his body, causing him to flex his wrists while operating the keyboard. Since the recommended seat height *HH* is 49 cm, a seat support of 11 cm is placed on the chair to allow him to sit more comfortably. Additionally, a base support of 18 cm is placed under the NBC and the tilt

Table 2. Adjustment recommendations for the two subjects

	Male (*BH* = 178 cm)	Female (*BH* = 162 cm)
Recommended seat height (cm)	49	42
Recommended work surface height (cm)	93	80
Distance between body and NBC (cm) (*measured from the front edge of NBC*)	35	28
Foot rest (cm)	-	-
Seat support (cm)	11	4
Base support (cm)	18	5
Tilt angle of NBC	25°	29°
Base-screen angle of NBC	125°	128°

Note: All decimal points have been rounded to the nearest integer.


Before
After

Figure 7. Side-view images of the male subject, before (left) and after (right) implementing adjustment recommendations


Before After

Figure 8. Side-view images of the female subject, before (left) and after (right) implementing adjustment recommendations

Table 3. RULA scores of body part postures

	Male		Female	
	Before	After	Before	After
Upper arm	1	1	2	1
Lower arm	2	2	2	2
Wrists	3	1	3	1
Neck	3	1	3	1
Trunk	1	1	1	1
Leg	1	1	1	1
Muscle use	1	1	1	1
Force/load	1	1	1	1
Table A score	3	2	3	2
Score C	5	4	5	4
Table B score	3	1	3	1
Score D	5	3	5	3
Grand score	**6**	**3**	**6**	**3**
Action Level	**Level 3**[a]	**Level 2**[b]	**Level 3**[a]	**Level 2**[b]

[a] *Action Level 3: Investigation and changes are required soon.*

[b] *Action Level 2: Further investigation is needed and changes may be required.*

angle of the base is set at 25°. The subject can rest his palms on the NBC to reduce stress on his shoulders. These adjustments help to improve both neck and wrist postures. It is also seen that by keeping the distance between his body and the NBC at 35 cm, the subject's body posture is now similar to that described in Section 2.

The female subject in Figure 8 has similar initial body posture to that of the male subject's. Her wrists are excessively bent during NBC operation. The top of the screen unit is also too low, causing her to bend her neck in order to view the screen. For this subject, the adjustment recommendations are: (1) adding a seat support and base support of 4 and 5 cm, respectively, (2) setting the tilt angle and screen angle at 29° and 128°, respectively, and (3) keeping the distance between the body and the NBC at 28 cm. By visually comparing the two postures (before and after adjustment), it is seen that both her neck and wrist postures are greatly improved. Wrist deviation is eliminated and neck flexion is reduced.

As for the quantitative comparison, the subjects' work postures are assessed using RULA. For the male subject, it is found that the RULA grand scores of the work posture before adjustment and the one after adjustment are 6 and 3, respectively. A reduction in the RULA grand score indicates that the posture is improved. For the female subject, the RULA grand scores of the work posture before adjustment and the one after adjustment are 5 and 3, respectively. Thus, the RULA analysis also confirms the effectiveness of the adjustment recommendations. See Table 3 for the detailed analysis.

6. CONCLUSION

During NBC operation, the user should sit with the back at an upright (or slightly reclined) position; shoulder flexion should not be more than 20°; the lower arms and hands should form a straight line; the lower legs should form the right angle (90°) with the upper legs; both feet should rest comfortably on the floor. For proper viewing, neck flexion should not be more than 10° and the viewing distance should be between 38 and 62 cm.

To achieve this recommended posture, two analytical algorithms for adjusting the NBC and the workstation are developed. The algorithms require the user's anthropometric data, physical dimensions of the NBC, and workstation constraints (i.e., seat height and work surface height). When there are no workstation constraints, the first algorithm determines the coordinates of reference body points for the correct seated posture. Additionally, it recommends the tilt angle of the NBC base unit, as well as the screen angle. The second algorithm is utilized when the workstation imposes constraints on the body posture. The algorithm compares the results to the actual seat and work surface heights. Then, it gives adjustment recommendations such as footrest, seat support, and base support to adjust the NBC and the workstation so that the recommended posture can be obtained.

The adjustment algorithms are validated by having two subjects set an NBC at a given workstation and using the algorithms to recommend necessary adjusttments. The digital images of the two subjects recorded both before and after adjustment show that the adjustment recommendations help to improve the body posture. The RULA analysis also confirms the effectiveness of the algorithms in improving the body posture.

Although the adjustment algorithms are based on the anthropometric data which 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. When the NBC user wears shoes, the shoe heal height raises their upper legs up above the seat, providing additional clearance to further prevent thigh compression. Thus, wearing shoes during NBC operation does not adversely affect the adjustment recommendations.

It is believed that using these analytical algorithms, NBC users can position the NBC and adjust the workstation so that they can sit with the correct body posture during NBC operation. Consequently, their fatigue and body discomforts due to poor work posture are expected to reduce, which will help to enhance workplace safety and job satisfaction.

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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.

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.

Sommerich, 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., 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.

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