ANALYTICAL ALGORITHMS FOR ADJUSTING BODY
ORIENTATION AND NOTEBOOK COMPUTER SETTINGS TO
OBTAIN ERGONOMIC SEATED POSTURE

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Abstract: A notebook computer (NBC) consists of a keyboard and a screen which are attached through a hinge joint. This design makes it difficult for an NBC user to adjust the NBC settings so that an ergonomic seated posture can be obtained. Two analytical adjustment algorithms are developed: (1) algorithm without workstation constraints, and (2) algorithm with workstation constraints. Based on anthropometric data of the NBC user, size of NBC (as determined from the size of the screen), and workstation data, the adjustment algorithm recommends not only the body orientation in terms of essential body joint angles and seat height, but also the NBC settings in terms of its distance from the NBC user, work surface height, NBC base tilt angle, and screen angle, to obtain the ergonomic seated posture while operating the NBC. Examples are also presented to compare the body orientations and NBC settings according to different genders (male and female), body sizes (P5, P50, and P95), and workstations.

1. INTRODUCTION

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 visual display terminal (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 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.

Sommerick et al. (2002) conducted a detailed study to evaluate the effects of the 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 apply the adjustment algorithm with workstation constraints to derive adjustment recommendations for male and female Thai NBC users based on two NBC screen sizes and two workstation heights.

2. RECOMMENDED WORK POSTURE

As recommended in the ANSI/HFS 100-1988 Standard (The Human Factors Society, 1988), 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 Nanthanvanij, 2004).

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.

Lueder (1996) revised the Rapid Upper Limb Assessment (RULA) technique developed by McAtamney and Corlett (1993) 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.

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°.

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.

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.
3. ANTHROPOMETRIC AND HARDWARE 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 5\(^{th}\), 50\(^{th}\), and 95\(^{th}\) percentiles.

Table 1. Selected Anthropometric Data of Thai Population (as Proportions of Body Height)

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Male</th>
<th></th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P5</td>
<td>P50</td>
<td>P95</td>
</tr>
<tr>
<td>Body height (( BH ), cm)</td>
<td>157.9</td>
<td>166.8</td>
<td>177.1</td>
</tr>
<tr>
<td>Eye height (sitting) (( IH ))</td>
<td>0.7054</td>
<td>0.7219</td>
<td>0.7336</td>
</tr>
<tr>
<td>Shoulder height (sitting) (( SH ))</td>
<td>0.5798</td>
<td>0.6134</td>
<td>0.6429</td>
</tr>
<tr>
<td>Length of upper arm (( UA ))</td>
<td>0.2027</td>
<td>0.2085</td>
<td>0.2122</td>
</tr>
<tr>
<td>Length of lower arm (( LA ))</td>
<td>0.1600</td>
<td>0.1668</td>
<td>0.1731</td>
</tr>
<tr>
<td>Length of hand (( HA ))</td>
<td>0.1140</td>
<td>0.1169</td>
<td>0.1193</td>
</tr>
<tr>
<td>Popliteal height (sitting) (( HH ))</td>
<td>0.2604</td>
<td>0.2685</td>
<td>0.2754</td>
</tr>
<tr>
<td>Length of upper leg (( UL ))</td>
<td>0.3305</td>
<td>0.3393</td>
<td>0.3463</td>
</tr>
<tr>
<td>Length of lower leg (( LL ))</td>
<td>0.2981</td>
<td>0.3054</td>
<td>0.3125</td>
</tr>
</tbody>
</table>

From Table 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. Note that the ranges are determined as mid-points between the body heights from two adjacent percentile values.

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

3.2 Body Reference Points

Selected body reference points are required by the algorithms. 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

\[\begin{align*}
AB &= \text{tilt angle of NBC base unit}, \\
AE &= \text{elbow angle, measured between the upper and lower arms}, \\
AS &= \text{shoulder flexion angle, measured between the trunk and upper arm}, \\
AV &= \text{viewing angle, measured between the horizontal line and the normal line of sight (at the screen top)}, \\
AW &= \text{wrist deviation angle, measured between the lower arm and hand}, \\
BS &= \text{screen angle, measured between the NBC base and screen units, and} \\
ES &= \text{incidence angle, measured between the normal line of sight and the screen surface,}
\end{align*}\]

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):**

\[\begin{align*}
I_x &= 5 \\
I_y &= IH
\end{align*}\]

**Shoulder joint (S):**

\[\begin{align*}
S_x &= 0 \\
S_y &= SH
\end{align*}\]

**Elbow joint (E):**

\[\begin{align*}
E_x &= S_x + (UA \times \sin AS) \\
E_y &= S_y - (UA \times \cos AS)
\end{align*}\]

**Wrist joint (W):**

\[\begin{align*}
W_x &= E_x + (LA \times \cos (AE - 90^\circ)) \\
W_y &= E_y + (LA \times \sin (AE - 90^\circ))
\end{align*}\]

**Fingertip (M):**

\[\begin{align*}
M_x &= E_x + [(0.75 \times HA) + LA \times \cos (AE - 90^\circ)] \\
M_y &= E_y + [(0.75 \times HA) + LA \times \sin (AE - 90^\circ)]
\end{align*}\]

**Ankle joint (A):**

\[\begin{align*}
A_x &= UL \\
A_y &= 0
\end{align*}\]

**Knee joint (K):**

\[\begin{align*}
K_x &= A_x \\
K_y &= A_y + LL
\end{align*}\]

**Hip Joint (H):**

\[\begin{align*}
H_x &= 0 \\
H_y &= K_y
\end{align*}\]

### 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.

**Home row (R):**

\[\begin{align*}
R_x &= M_x \\
R_y &= M_y
\end{align*}\]

**Front edge (F):**

\[\begin{align*}
F_x &= R_x - (RL \times \cos AB) \\
F_y &= R_y - (RL \times \sin AB)
\end{align*}\]

**Rear edge (B):**

\[\begin{align*}
B_x &= F_x + (BL \times \cos AB) \\
B_y &= F_y + (BL \times \sin AB)
\end{align*}\]

**Top edge (T):**

\[\begin{align*}
T_x &= B_x + \{SL \times \sin (BS - 90^\circ)\} \\
T_y &= B_y + \{SL \times \cos (BS - 90^\circ)\}
\end{align*}\]

### 4. ADJUSTMENT ALGORITHMS

Two adjustment algorithms are developed. 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 that 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.

4.1 Algorithm without Workstation Constraints

4.1.1 Initialization

- $AS = AW = 0^\circ$
- $AE = 90^\circ$
- $BS = 120^\circ$
- The NBC base unit is positioned on the same axis as the lower arm – hand axis (i.e., $AB = 90^\circ + AS - AE$)

4.1.2 Adjustment Procedure

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 $ES = 90^\circ$:
   - If $ES = 90^\circ$, proceed to Step A6.
   - If $ES < 90^\circ$, decrease $BS$ by 1°. Then, check the new $BS$.
     - If $BS > 90^\circ$, determine $T_x, T_y,$ and $ES$. Repeat Step A5.
     - If $BS = 90^\circ$, determine $T_x, T_y,$ and $ES$. If $ES = 90^\circ$, proceed to Step A6.
     Otherwise, stop (infeasible posture).
   - If $ES > 90^\circ$, increase $BS$ by 1°.
     - If $BS < 180^\circ$, determine $T_x, T_y,$ and $ES$. Repeat Step A5.
     - If $BS = 180^\circ$, determine $T_x, T_y,$ and $ES$. If $ES = 90^\circ$, proceed to Step A6.
     Otherwise, stop (infeasible posture).
A7. Check $AV$.
   - If $AV \leq 10^\circ$, determine the viewing distance $VD$.
     - If $38 \leq VD \leq 62$ cm, go to Step A16.
     - Otherwise, proceed to Step A8.
   - If $AV > 10^\circ$, proceed to Step A8.
A8. Set $VD = 62$ cm and $AV = 10^\circ$. Then, determine $T_x$ and $T_y$.
A9. Set $ES = 90^\circ$. 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 $F_y$.
A14. Check $AS$.
   - If $AS \leq 20^\circ$, go to Step A16.
   - If $AS > 20^\circ$, 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.
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.

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 recommendations that satisfy the workstation constraints.

The first fifteen 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.

4.3 Validation

A 178-cm tall, male subject is given a notebook computer with its screen size of 11.1 inches. Then, he 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. 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. The list of adjustment recommendations is shown below.

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>49 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended seat height</td>
<td>49 cm</td>
</tr>
<tr>
<td>Recommended work surface height</td>
<td>93 cm</td>
</tr>
<tr>
<td>Distance between body and NBC</td>
<td>35 cm</td>
</tr>
<tr>
<td>Footrest height:</td>
<td>-</td>
</tr>
<tr>
<td>Seat support height:</td>
<td>11 cm</td>
</tr>
<tr>
<td>Base support height:</td>
<td>18 cm</td>
</tr>
<tr>
<td>NBC tilt angle:</td>
<td>25°</td>
</tr>
<tr>
<td>Screen angle:</td>
<td>125°</td>
</tr>
</tbody>
</table>

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. Figure 2 shows the comparisons of body postures of the subjects. 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).

It is seen that the male subject has to sit on a low chair \((AHH = 38\, \text{cm})\). 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 \((AWH = 75\, \text{cm})\) 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 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.

As for the quantitative comparison, the subject’s work postures are assessed using RULA. 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. See Table 3 for the detailed analysis.
Figure 2. Side-View Images of the Male Subject, Before (left) and After (right) Implementing Adjustment Recommendations.

Table 3. RULA Scores of Body Part Postures

<table>
<thead>
<tr>
<th>RULA</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper arm</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Lower arm</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Wrists</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Neck</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Trunk</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Leg</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Muscle use</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Force/load</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Table A score</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Score C</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Table B score</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Score D</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Grand score</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

Action Level

- Level 3*: Investigation and changes are required soon.
- Level 2*: Further investigation is needed and changes may be required.

5. ADJUSTMENT RECOMMENDATIONS

The adjustment algorithm with workstation constraints is used to generate adjustment recommendations based on the following data:

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Height</td>
<td>P5, P50, and P95 (see Table 1)</td>
<td></td>
</tr>
<tr>
<td>NBC size</td>
<td>11-inch NBC</td>
<td></td>
</tr>
<tr>
<td>15-inch NBC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workstation</td>
<td>Stone table-and-chair set (seat height = 40 cm; work surface height = 68 cm)</td>
<td></td>
</tr>
<tr>
<td>Wooden table-and-chair set (seat height = 45 cm; work surface height = 76 cm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The adjustment recommendations are shown in Table 4.
Table 4. Summary of Adjustment Recommendations

(a) Stone Table-and-Chair Set

<table>
<thead>
<tr>
<th>NBC Size</th>
<th>Gender</th>
<th>Body Height</th>
<th>Adjustment Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Footrest</td>
</tr>
<tr>
<td>11.1-inch NBC</td>
<td>Male</td>
<td>P5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>P5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
<tr>
<td>15-inch NBC</td>
<td>Male</td>
<td>P5</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>P5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
</tbody>
</table>

(b) Wooden Table-and-Chair Set

<table>
<thead>
<tr>
<th>NBC Size</th>
<th>Gender</th>
<th>Body Height</th>
<th>Adjustment Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Footrest</td>
</tr>
<tr>
<td>11.1-inch NBC</td>
<td>Male</td>
<td>P5</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>P5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>2</td>
</tr>
<tr>
<td>15-inch NBC</td>
<td>Male</td>
<td>P5</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>P5</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P50</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P95</td>
<td>4</td>
</tr>
</tbody>
</table>

*1,2 The unit is cm. *3 The unit is degree.
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 a male subject set an NBC at a given workstation and using the algorithms to recommend necessary adjustments. 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.

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.

7. ACKNOWLEDGMENTS

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8. REFERENCES


