Worksheets for Computing Recommended Notebook Computer and Workstation Adjustments

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This paper discusses the design and development of worksheets for helping notebook computer (NBC) users to compute NBC and workstation adjustments so as to assume an appropriate seated posture. The worksheets (one for male users, the other for female ones) require the following information: body height, NBC screen size, work surface height, and seat height. The worksheets contain tables for estimating recommended NBC base angle, NBC screen angle, body–NBC distance, work surface height, and seat height. Additionally, they include flow charts to help NBC users to determine necessary adjustment accessories and their settings.

notebook computer operation   work posture   musculoskeletal disorders   office ergonomics

1. INTRODUCTION

Numerous office employees nowadays use notebook computers (NBCs) to perform their assigned tasks. Owing to their light weight, small size, portability, and battery-powered operation, NBCs have quickly become very popular among computer users. Lower prices and increased performance specifications have also made NBCs a popular business and educational tool among office employees and university students, respectively. Given the current research results linking desktop computer use to musculoskeletal symptoms and syndromes in office employees, it is reasonable to suspect that NBC operation is at least equally likely to contain musculoskeletal risks.

Musculoskeletal problems such as neck and shoulder discomfort are common among office employees especially those who use the computer on a regular basis [1]. Discomfort is a symptom at the first stage [2]. If the symptom is ignored, dis-comfort can develop into severe pain or a chronic disability, which has an impact on rehabilitation services, lost work time, poor work quality, low work performance, decreased motivation, and stress from sickness [3]. Musculoskeletal discomfort is the result of various work-related factors. A poor workstation, awkward work posture, static work posture, prolonged work duration, inadequate resting time, and lack of work position variety are known to contribute to musculoskeletal discomfort [4]. Discomfort can also be intensified by the situation at work, including physical demands at work, work organization, and psychological stress and depression from work [5].

Ergonomics researchers suggested that visual display terminal (VDT) workstations for desktop computers, which lead to awkward or constrained work postures, predispose computer users to musculoskeletal injuries, and that persistent musculoskeletal problems are related to poor workstation design and adjustability [6].

Several research studies were conducted to give recommendations and guidelines about input/output devices, computer workstation, and seated posture, resulting in Standard No. ANSI/HFES 100-2007 [7]. Unfortunately, the recommendations in Standard No. ANSI/HFES 100-2007 are intended for the desktop computer use and workstations regularly used in office workplaces. Limited information about ergonomic recommendations is available for employees who work with NBCs [8]. Because of its hinge design, the height of the NBC base and screen units cannot be independently adjusted. This design could lead to awkward work postures with excessive stress in the neck and shoulder regions.

Physical implications of NBC operation on body posture have been reported [6, 9, 10, 11]. Straker, Jones, and Miller compared body postures during desktop computer and NBC operations [10]. The results revealed that in terms of postural constraints and discomfort, desktop computer users felt better even after 20 min of computer use. Horikawa did a quantitative examination of the relation between screen height and trapezius muscle hardness on subjects using desktop computers and NBCs [12]. The results showed that with 15 min of data entry work on NBCs, the hardness of trapezius muscle increased. Straker, Pollock, and Mangharam suggested that NBC users would assume postures that would compromise their typing posture either by increasing neck flexion to view a "too-low" screen or increasing shoulder and elbow flexion to reach a "too-high" keyboard [13]. Harbison and Forrester also found that NBC users required an increased forward head inclination to adequately operate the NBC due to its lack of adjustability [6]. In their study, all NBC users had neck flexion over 30° greater than the neck posture recommended in Standard No. 3590.2–1990 [14]. Sommerich, Starr, Smith, et al. conducted a detailed study to evaluate the effects of NBC on body posture when the NBC was operated in a stand-alone condition and with inexpensive ordinary peripheral input devices such as external keyboard, mouse, and numeric pads [15]. The results showed that in the stand-alone condition, the body postures were more deviated from the neu-

tral positions. They concluded that the use of external peripheral devices could reduce stress on the neck.

A computerized VDT workstation adjustment tool, called IntelAd, was previously developed to recommend seat height, keyboard height, and monitor height for desktop computer users [16, 17]. The same adjustment algorithm as that in IntelAd was used earlier in Nanthavanij to evaluate several types of VDT workstation and to develop the body height–workstation settings matrix to assist VDT users in adjusting their workstation [18]. Rurkhamet and Nanthavanij developed an analytical design method for computing workstation settings and positioning computer accessories so as to help VDT users to sit with the appropriate posture [19]. Later, Rurkhamet and Nanthavanij developed a rule-based decision support system, called EQ-DeX, based on their analytical algorithm. EQ-DeX provides quantitative adjustment recommendations and displays line figures to illustrate the resulting workstation settings and computer accessories layout [20].

Jalil and Nanthavanij developed two analytical algorithms, with and without workstation constraints, to compute recommended adjustments such as footrest height, seat support height, NBC base support height, etc., so that the appropriate work posture during NBC operation could be obtained [21]. Jamjumrus and Nanthavanij also used Jalil and Nanthavanij's adjustment algorithm with workstation constraints as an ergonomic intervention tool to improve NBC users' work postures [22]. They used the Rapid Upper Limb Assessment (RULA) technique [23] to evaluate the work postures both before and after the ergonomic intervention. According to the RULA grand scores, there was a significant improvement in work posture. Jalil and Nanthavanij developed a computer program, called PostureAdjuster, to provide practical recommendations for adjusting the NBC and workstation to avoid awkward work postures during NBC operation [24]. PostureAdjuster is capable of evaluating the current work posture, generating practical adjustment recommendations, and performing a work posture analysis with RULA.

This paper discusses the design and construction of simple worksheets for helping NBC users to compute adjustment settings for the NBC and workstation so as to assume the appropriate seated posture. It gives two numerical examples with step-by-step explanations for using the worksheets. Lastly, the recommended adjustments computed from the worksheets are compared to those obtained from PostureAdjuster to evaluate their effectiveness.

2. RECOMMENDED SEATED POSTURE

The base and screen units of the NBC are connected by hinges, which prohibit the height of the base (or keyboard) and screen (or monitor) from being adjusted independently. This hardware design imposes restriction on the NBC user's work posture. If the screen is positioned such that the user's neck posture is appropriate, the upper arms 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 elbow height, the wrist posture will be neutral but the neck must be flexed excessively to view the screen.

Lueder [25] revised the RULA technique previously developed by McAtammy and Corlett [23] so that it could be used to assess the VDT user's work posture during computer use. 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 also mentioned that neck flexion of over 15° caused fatigue when operating VDTs [26]. According to Straker et al., at neck angles of 11°–16°, the load on the neck is 280 N and it increases as the neck angle is increased [10]. Readers should note that neck flexion is imperative to view the screen so that the incidence angle of the line of sight is perpendicular to the screen surface.

Straker and Pollock showed comparisons between shoulder angles of 0° and 30° over a 20-min work period and concluded that the shoulder flexion of 0° was preferable to that of 30° since their subjects reported six times less discomfort [13]. 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, Smith, and Cohen recommended that an acceptable range of the viewing distance for VDT operation be 45–70 cm [27]. Saito, Miyao, Konto, et al. conducted an evaluation of working conditions and musculoskeletal posture on 10 subjects by comparing viewing distance, viewing angle, head angle, neck angle, and electromyography (EMG) on neck, back, and shoulder muscles [28]. For the viewing distance, they reported that NBC operation resulted in the viewing distance that was 8 cm shorter than the distance for desktop computer operation. Later, Moffet, Hagberg, Hansson-Risberg, et al. evaluated working postures while operating NBCs [29] and confirmed Saito et al.'s findings [28].

Although the recommended seated posture in Standard No. ANSI/HFES 100-2007 is intended for desktop computer users [7], it can be adapted with some modifications based on the research on NBC operations discussed earlier. Jalil and Nanthavanij described an appropriate work posture during NBC operation as follows [21]:

1. The NBC user should sit with the back at an upright (or slightly reclined, if the backrest is provided) position.
2. Neck flexion should not exceed 10°.
3. Shoulder flexion should not exceed 20°
4. Elbow flexion should be ~90°
5. The lower arms and hands should form a straight line, thus imposing no deviation around the wrists.
6. The lower legs should form the right angle (90°) with the upper legs.
7. Both feet should rest comfortably on the floor.
8. The viewing distance should be 38–62 cm.

Readers should note that neck and shoulder postures are slightly compromised since the base and screen units of NBCs cannot be independently adjusted. However, according to the revised RULA, such neck and shoulder angles still yield lower RULA scores than those from other angles and are considered acceptable. NBC users need to

be warned that sitting with the recommended posture would still cause fatigue and musculo-skeletal discomfort in certain body parts, especially when a work session is long. They should keep the use of NBCs short. For prolonged NBC operation, frequent rest breaks are strongly recommended.

The NBC user's seated posture is influenced by the user's body height, NBC size, work surface height, and seat height. It is highly unlikely that any NBC user can sit with the appropriate seated posture without requiring any adjustments [21, 24]. The recommended adjustments can be divided into two groups. The first group consists of three adjustments of the NBC: NBC base tilt angle, screen angle, and body–NBC distance. The second group consists of three adjustments of the workstation: NBC base support height, seat support height, and footrest height. Nanthavanij, Jalil, and Ammarapala briefly summarized the six NBC and workstation adjustments [30]:

- NBC base (tilt) angle: the angle between the work surface (or NBC base support) and the NBC base. For example, if the NBC is laid flat on the workstation (or NBC base support), its tilt angle is 0°;
- screen angle: the angle between the NBC base and its screen. When the NBC lid is closed, this angle is 0°;
- body–NBC distance: clearance between the user's body and NBC. It is measured horizontally from the front surface of the trunk to the front edge of NBC base;
- NBC base support: a platform (or stand) that is placed on the workstation right underneath the NBC to raise its height so that the user can operate the keyboard and view the screen with the appropriate upper extremity postures (e.g., shoulder, elbow, wrist, and neck);
- seat support: a seat cushion that is placed on a chair seat to raise the seat height so that the user can sit with both upper and lower legs forming the right angle at the knee joints and both feet rest comfortably on the floor;
- footrest: a platform (horizontal or inclined) that is placed on the floor right underneath both feet to prevent them from dangling.

Note that to obtain the recommended seated posture, some adjustments require the use of adjustment accessories.

3. WORKSHEETS FOR NBC AND WORKSTATION ADJUSTMENTS

3.1. Concepts

The design of the worksheets is based on the concepts of functionality, practicality, and usability.

3.1.1. Functionality

The worksheets must give valid recommendations to help NBC users to adjust the NBC and workstation so that they can sit with the appropriate seated posture. Additionally, the worksheets must accommodate both male and female NBC users with different body height and NBCs of various sizes. On the basis of actual work surface height and seat height, the adjustment worksheets must recommend necessary adjustment accessories, including their estimated settings.

3.1.2. Practicality

The use of the worksheets must be practical. The required data must be relatively easy to obtain. The worksheets should contain appropriate tables, graphs, or flow charts that can assist NBC users in computing the necessary adjustments. While some computations might be required, they should be simple mathematical operations (e.g., addition and subtraction).

3.1.3. Usability

The worksheets must be simple to use. Their design and layout must not confuse NBC users. All steps must follow the computation sequence. With some training, NBC users must be able to obtain the correct results within reasonable time. They must be guided from the first step to the last step of the computation procedure. All recommended adjustments must be explicitly summarized for convenient implementation.

3.2. Computation of NBC Adjustments

None of the three NBC adjustments are affected by the workstation that the NBC user is sitting at. That is, irrespective of work surface height and seat height, the three NBC adjustments depend only on the NBC user's gender, body height, and NBC size. As a result, the adjustment algorithm without workstation constraints [21] can be used to generate those NBC adjustments for various combinations of the NBC user's gender, body height, and NBC size. Readers should note that this paper expresses the size of the NBC in terms of its screen size.

Tables 1–3 show the recommended NBC base angle (degrees), screen angle (degrees), and body–NBC distance (centimeters) for both male and female users, with their respective body height of 155–185 and 145–175 cm. Only five NBC sizes are considered here since they are the most common ones in Thailand. For convenience,

TABLE 1. Recommended Notebook Computer (NBC) Base Angle (°)

Male						Female					
	NBC Screen Size (")						NBC Screen Size (")				
BH (cm)	11.1	12.1	13.3	14	15.4	BH (cm)	11.1	12.1	13.3	14	15.4
155–158	30	25	23	21	16	145–149	25	21	18	15	11
159–162	31	27	23	21	17	150–154	26	22	19	17	13
163–167	27	23	20	19	15	155–159	28	24	20	18	14
168–171	28	24	21	20	17	160–164	29	24	21	20	15
172–180	25	22	20	19	16	165–169	30	25	22	21	17
181–185	26	24	22	21	18	170–175	31	27	24	22	19

Notes. BH = body height.

TABLE 2. Recommended Notebook Computer (NBC) Screen Angle (°)

Male						Female					
	NBC Screen Size (")						NBC Screen Size (")				
BH (cm)	11.1	12.1	13.3	14	15.4	BH (cm)	11.1	12.1	13.3	14	15.4
155–158	130	126	123	120	116	145–149	125	121	118	116	111
159–162	131	126	123	122	117	150–154	127	122	119	117	113
163–167	127	123	120	118	115	155–159	128	124	121	118	114
168–171	128	124	122	120	117	160–164	128	124	121	120	115
172–180	125	122	120	119	116	165–169	130	125	123	121	117
181–185	126	124	122	121	118	170–175	131	127	124	122	119

Notes. BH = body height.

TABLE 3. Recommended Body–Notebook Computer (NBC) Distance (cm)

Male						Female					
	NBC Screen Size (")						NBC Screen Size (")				
BH (cm)	11.1	12.1	13.3	14	15.4	BH (cm)	11.1	12.1	13.3	14	15.4
155–158	27	26	25	25	24	145–149	25	24	23	23	21
159–162	28	26	26	26	25	150–154	27	25	25	24	23
163–167	30	29	28	29	26	155–159	28	26	26	26	24
168–171	31	30	29	30	26	160–164	28	27	29	27	26
172–180	34	32	30	28	25	165–169	29	28	29	29	26
181–185	35	31	29	28	24	170–175	31	29	29	29	26

Notes. BH = body height.

PostureAdjuster is used to generate the recommended adjustments. They are rounded to the nearest integer for ease of implementation. Body height is grouped into six ranges. To obtain the adjustments for individual body height ranges, some values might need to be modified.

3.3. Computation of Ideal (Recommended) Work Surface Height and Seat Height

Ideally, NBCs can be used at any place. This flexibility makes it very difficult to determine necessary workstation adjustments. In Jalil and Nanthavanij, the adjustment algorithm without workstation constraints was used to compute the ideal (or recommended) work surface height and seat height, which would enable the NBC user to sit appropriately [21, 24]. Next, they were compared to the actual height. Necessary workstation adjustments could then be recommended.

Following the same approach, PostureAdjuster is again used to generate the ideal work surface

height and seat height. Tables 4–5 summarize the results. Each table shows ideal values for both male and female NBC users. In the same fashion, the computed values are rounded to the nearest integer.

3.4. Computation of Workstation Adjustments

A typical NBC workstation consists of a chair and a table. The chair that the NBC user sits on can be fixed (seat height is fixed) or adjustable (seat height is adjustable within a certain range). The table is usually fixed. At any given NBC workstation, the actual table height and seat height must be measured. By comparing the ideal (recommended) height and the actual height, necessary workstation adjustments can be computed. In practice, the use of NBC base support, seat support, and footrest is normally required.

There are nine possible conditions to be considered (RSH = recommended seat height, ASH =

TABLE 4. Ideal Work Surface (Table) Height (cm)

Male						Female					
	NBC Screen Size (")						NBC Screen Size (")				
BH (cm)	11.1	12.1	13.3	14	15.4	BH (cm)	11.1	12.1	13.3	14	15.4
155–158	73	69	68	67	65	145–149	67	64	62	61	59
159–162	76	72	70	69	67	150–154	70	67	65	64	62
163–167	82	78	76	75	73	155–159	75	72	69	69	66
168–171	85	81	79	78	75	160–164	80	76	74	74	71
172–180	91	87	86	85	82	165–169	83	79	78	77	74
181–185	96	92	90	89	87	170–175	87	83	81	80	77

Notes. BH = body height.

TABLE 5. Ideal Seat Height (cm)

Male						Female					
	NBC Screen Size (")						NBC Screen Size (")				
BH (cm)	11.1	12.1	13.3	14	15.4	BH (cm)	11.1	12.1	13.3	14	15.4
155–158	41	41	41	41	41	145–149	36	36	36	36	36
159–162	42	42	42	42	42	150–154	38	38	38	38	38
163–167	44	44	44	44	44	155–159	40	40	40	40	40
168–171	46	46	46	46	46	160–164	42	42	42	42	42
172–180	48	48	48	48	48	165–169	43	43	43	43	43
181–185	50	50	50	50	50	170–175	45	45	45	45	45

Notes. BH = body height.

actual seat height, RTH = recommended table height, ATH = actual table height).

1. RSH = ASH
    and
    RTH = ATH
2. RSH = ASH
    and
    RTH > ATH
3. RSH = ASH
    and
    RTH < ATH
4. RSH > ASH
    and
    RTH = ATH
5. RSH > ASH
    and
    RTH > ATH
6. RSH > ASH
    and
    RTH < ATH
7. RSH < ASH
    and
    RTH = ATH
8. RSH < ASH
    and
    RTH > ATH
9. RSH < ASH
    and
    RTH < ATH

Jalil and Nanthavanij developed adjustment procedures for those nine conditions, which result in the recommended settings for the NBC base support, seat support, and footrest, whichever necessary, based on the use of a fixed chair [21]. When an adjustable chair is used, the procedures must be modified to recommend logical adjustments. That is, the use of a seat support becomes necessary only when the RSH exceeds the maximum height of the chair seat.

To assist NBC users in computing the recommended adjustments, flow charts are constructed based on the nine conditions. NBC users can choose an appropriate flow chart and perform the computations as guided by the chart.

3.5. Final Worksheet Design

Since there are several tables and flow charts involved in the computation procedure, the worksheets for male and female NBC users are constructed separately with a similar layout. Each worksheet comprises the following sections.

Section 1

This section contains the information on the NBC user, NBC, and workstation.

User:
   name
   body height
NBC:
   screen size
Workstation:
   table height
   seat height

(For an adjustable chair, both the minimum and maximum height must be known.)

Section 2

Step 1: determine recommended NBC base angle
Step 2: determine recommended NBC screen angle
Step 3: determine recommended body–NBC distance
Step 4: determine RTH
Step 5: determine RSH

In each step, the user will read the value from the table according to the NBC user's body height, and NBC screen size.

Section 3

Step 6: adjust seat height (for an adjustable chair)
Step 7: determine recommended adjustments

In step 7, three flow charts are given to guide the user in computing the recommended adjustments (see Figure 1).

Step 8: consider the seat support again (for an adjustable chair and if necessary)

Section 4

Step 9: summarize recommended adjustments

In this section, the recommended adjustments from sections 2 and 3 are summarized. The users can then adjust their NBCs and workstations accordingly.

Figures 2–3 show the worksheets for male and female NBC users, respectively. Readers can see that the worksheets contain blank spaces, where the user can fill in the chosen or computed values in each of the nine steps.
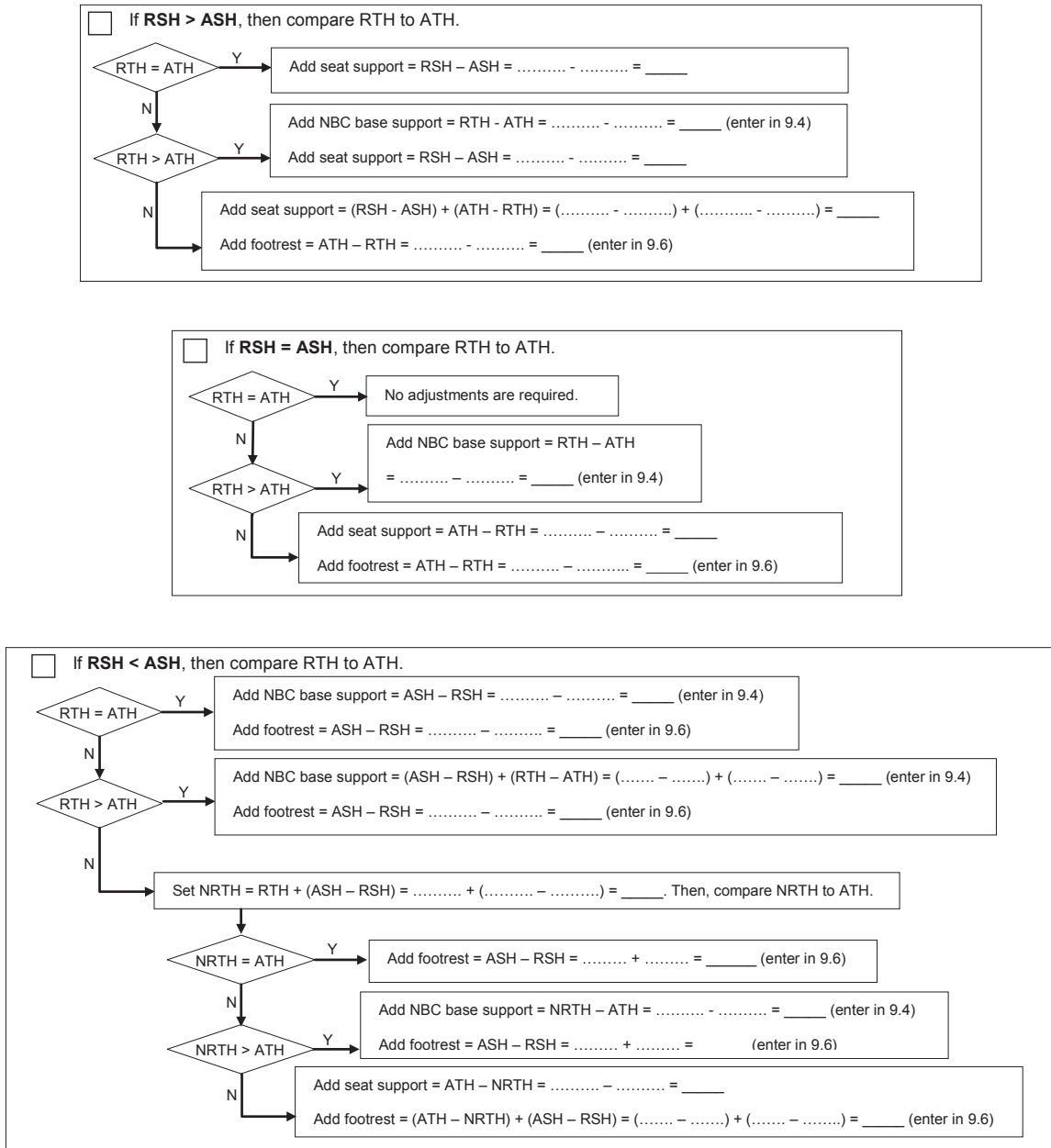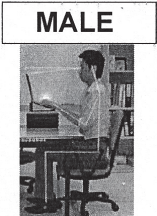

Figure 1. Flow charts for computing recommended adjustments. *Notes.* RSH = recommended seat height, ASH = actual seat height, RTH = recommended table height, ATH = actual table height, NRTH = new recommended table height.

Worksheet for Notebook Computer (NBC) and Workstation Adjustments

MALE

Name: _____

NBC Screen Size: _____"

Actual Table Height (ATH): _____ cm.

Actual Seat Height (ASH): _____ cm.

Body Height: _____ cm.

For Adjustable Seat:

Minimum Seat Height: _____ cm.

Maximum Seat Height: _____ cm.

If the user is shorter than 155 cm, set his body height as 155 cm.
If the user is taller than 185 cm, set his body height as 185 cm.

Step1: Determine recommended NBC base angle ①

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
155-158	30	25	23	21	16
159-162	31	27	23	21	17
163-167	27	23	20	19	15
168-171	28	24	21	20	17
172-180	25	22	20	19	16
181-185	26	24	22	21	18

Recommended NBC base angle = _____° (enter in 9.1)

Step2: Determine recommended NBC screen angle ②

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
155-158	130	126	123	120	116
159-162	131	126	123	122	117
163-167	127	123	120	118	115
168-171	128	124	122	120	117
172-180	125	122	120	119	116
181-185	126	124	122	121	118

Recommended NBC screen angle = _____° (enter in 9.2)

Step3: Determine recommended body-NBC distance ③

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
155-158	27	26	25	25	24
159-162	28	26	26	26	25
163-167	30	29	28	29	26
168-171	31	30	29	30	26
172-180	34	32	30	28	25
181-185	35	31	29	28	24

Recommended body-NBC dist. = ____ cm. (enter in 9.3)

Step4: Determine recommended table height (RTH) ④

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
155-158	73	69	68	67	65
159-162	76	72	70	69	67
163-167	82	78	76	75	73
168-171	85	81	79	78	75
172-180	91	87	86	85	82
181-185	96	92	90	89	87

Recommended table height (RTH) = _____ cm.
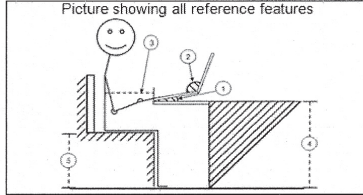
Picture showing all reference features

Step5: Determine recommended seat height (RSH) ⑤

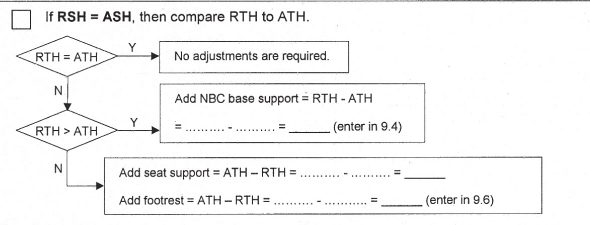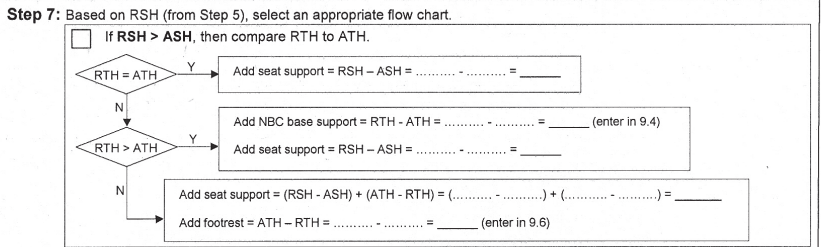| Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
155-158	41	41	41	41	41
159-162	42	42	42	42	42
163-167	44	44	44	44	44
168-171	46	46	46	46	46
172-180	48	48	48	48	48
181-185	50	50	50	50	50

Recommended seat height (RSH) = _____ cm.

Step 6: For fixed-height seat, skip to Step 7. Otherwise, check the following.

☐ If **min. height ≤ RSH ≤ max. height**,
→ Set ASH = RSH = _____

☐ If **RSH < min. height**,
→ Set ASH = min. height = _____

☐ If **RSH > max. height**,
→ Set ASH = max. height = _____

Step 7: Based on RSH (from Step 5), select an appropriate flow chart.

☐ If **RSH > ASH**, then compare RTH to ATH.

RTH = ATH —Y→ Add seat support = RSH – ASH = ... - .... = _____

↓N

RTH > ATH —Y→ Add NBC base support = RTH - ATH = ... - .... = _____ (enter in 9.4)
Add seat support = RSH – ASH = ... - .... = _____

↓N

Add seat support = (RSH - ASH) + (ATH - RTH) = (......... - ....) + (......... - ....) = _____
Add footrest = ATH – RTH = ... - .... = _____ (enter in 9.6)

☐ If **RSH = ASH**, then compare RTH to ATH.

RTH = ATH —Y→ No adjustments are required.

↓N

RTH > ATH —Y→ Add NBC base support = RTH - ATH
= .... - .... = _____ (enter in 9.4)

↓N

Add seat support = ATH – RTH = ... - .... = _____
Add footrest = ATH – RTH = ... - .... = _____ (enter in 9.6)

☐ If **RSH < ASH**, then compare RTH to ATH.

RTH = ATH —Y→ Add NBC base support = ASH – RSH = ... - .... = _____ (enter in 9.4)
Add footrest = ASH – RSH = ... - .... = _____ (enter in 9.6)

↓N

RTH > ATH —Y→ Add NBC base support = (ASH - RSH) + (RTH - ATH) = (...... - ......) + (...... - ......) = _____ (enter in 9.4)
Add footrest = ASH – RSH = ... - .... = _____ (enter in 9.6)

↓N

Set NRTH = RTH + (ASH - RSH) = ... + (......... - ....) = _____ . Then, compare NRTH to ATH.

NRTH = ATH —Y→ Add footrest = ASH – RSH = ... + ... = _____ (enter in 9.6)

↓N

NRTH > ATH —Y→ Add NBC base support = NRTH – ATH = ... - .... = _____ (enter in 9.4)
Add footrest = ASH – RSH = ... + ... = _____ (enter in 9.6)

↓N

Add seat support = ATH – NRTH = ... - .... = _____
Add footrest = (ATH – NRTH) + (ASH – RSH) = (...... – ......) + (...... - ......) = _____ (enter in 9.6)

Step 8: Check the following.

☐ For **fixed height seat**, enter seat support (from Step 7) in (9.5).

☐ For **adjustable seat**, Set NSH = ASH (from Step 6) + seat support (from Step 7)
= .... + ... = _____ . Then, check the following.

☐ If min. height ≤ NSH ≤ max. height,
→ Enter NSH in (9.0).

☐ If NSH > max. height,
→ Enter max. height in (9.0).
→ Add seat support = NSH – max. height
= .... - .... = _____ (enter in 9.5)
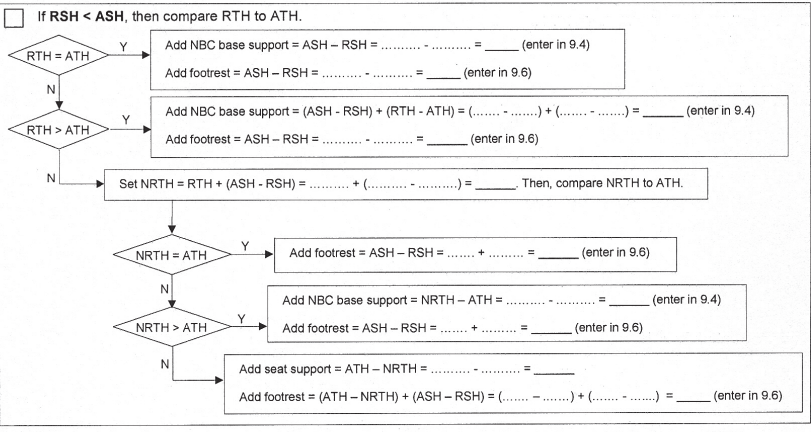
Step 9: Summary of Recommended Adjustments

9.0 Adjust seat height to _____ cm.

9.1 Rec. NBC base angle: _____°

9.2 Rec. NBC screen angle: _____°

9.3 Rec. body-NBC distance: _____ cm.

9.4 Rec. NBC base support height: _____ cm.

9.5 Rec. seat support height: _____ cm.

9.6 Rec. footrest height: _____ cm.

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Figure 2. Final worksheet for male notebook computer (NBC) users. *Notes.* RSH = recommended seat height, ASH = actual seat height, RTH = recommended table height, ATH = actual table height, NRTH = new recommended table height.

Worksheet for Notebook Computer (NBC) and Workstation Adjustments

FEMALE

Name: _____ Body Height: _____ cm.

NBC Screen Size: _____"

Actual Table Height (ATH): _____ cm.

Actual Seat Height (ASH): _____ cm.

For Adjustable Seat:

Minimum Seat Height: _____ cm.

Maximum Seat Height: _____ cm.

If the user is shorter than 145 cm, set her body height as 145 cm.
If the user is taller than 175 cm, set her body height as 175 cm.

Step1: Determine recommended NBC base angle ①

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
145-149	25	21	18	15	11
150-154	26	22	19	17	13
155-159	28	24	20	18	14
160-164	29	24	21	20	15
165-169	30	25	22	21	17
170-175	31	27	24	22	19

Recommended NBC base angle = _____° (enter in 9.1)

Step2: Determine recommended NBC screen angle ②

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
145-149	125	121	118	116	111
150-154	127	122	119	117	113
155-159	128	124	121	118	114
160-164	128	124	121	120	115
165-169	130	125	123	121	117
170-175	131	127	124	122	119

Recommended NBC screen angle = _____° (enter in 9.2)

Step3: Determine recommended body-NBC distance ③

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
145-149	25	24	23	23	21
150-154	27	25	25	24	23
155-159	28	26	26	26	24
160-164	28	27	29	27	26
165-169	29	28	29	29	26
170-175	31	29	29	29	26

Recommended body-NBC dist. = ____ cm. (enter in 9.3)

Step4: Determine recommended table height (RTH) ④

Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
145-149	67	64	62	61	59
150-154	70	67	65	64	62
155-159	75	72	69	69	66
160-164	80	76	74	74	71
165-169	83	79	78	77	74
170-175	87	83	81	80	77

Recommended table height (RTH) = _____ cm.
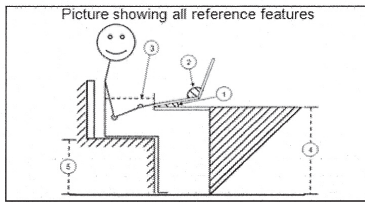
Picture showing all reference features

Step5: Determine recommended seat height (RSH) ⑤

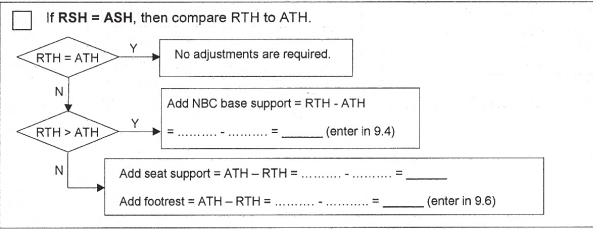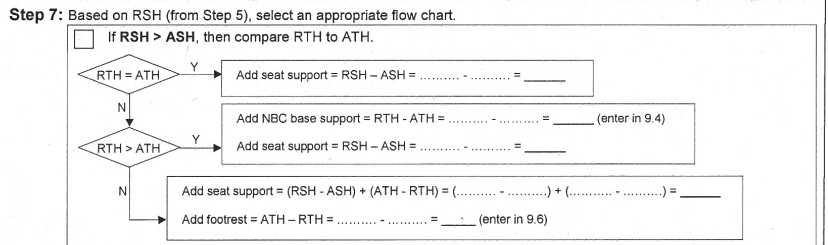| Body Height	NBC Screen Size				
	11.1"	12.1"	13.3"	14"	15.4"
145-149	36	36	36	36	36
150-154	38	38	38	38	38
155-159	40	40	40	40	40
160-164	42	42	42	42	42
165-169	43	43	43	43	43
170-175	45	45	45	45	45

Recommended seat height (RSH) = _____ cm.

Step 6: For fixed-height seat, skip to Step 7. Otherwise, check the following.

☐ If min. height ≤ RSH ≤ max. height,
→ Set ASH = RSH = _____

☐ If RSH < min. height,
→ Set ASH = min. height = _____
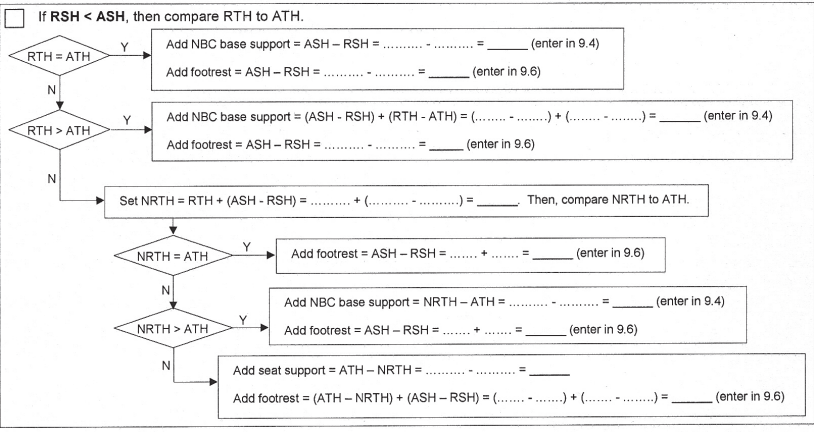
☐ If RSH > max. height,
→ Set ASH = max. height = _____

Step 7: Based on RSH (from Step 5), select an appropriate flow chart.

☐ If RSH > ASH, then compare RTH to ATH.

RTH = ATH —Y→ Add seat support = RSH – ASH = ... – .... = _____

N

Add NBC base support = RTH - ATH = ... – .... = _____ (enter in 9.4)

RTH > ATH —Y→ Add seat support = RSH – ASH = ... – .... = _____

N

Add seat support = (RSH - ASH) + (ATH - RTH) = (......... – ....) + (......... – ....) = _____

Add footrest = ATH – RTH = ... – .... = _____ (enter in 9.6)

☐ If RSH = ASH, then compare RTH to ATH.

RTH = ATH —Y→ No adjustments are required.

N

RTH > ATH —Y→ Add NBC base support = RTH - ATH
= .... – .... = _____ (enter in 9.4)

N

Add seat support = ATH – RTH = ... – .... = _____

Add footrest = ATH – RTH = ... – .... = _____ (enter in 9.6)

Step 8: Check the following.

☐ For **fixed height seat**, enter seat support in (9.5)

☐ For **adjustable seat**, Set NSH = ASH (from Step 6) + seat support (from Step 7)
= .... + ... = _____. Then, check the following.

☐ If min. height ≤ NSH ≤ max. height,
→ Enter NSH in (9.0)

☐ If NSH > max. height,
→ Enter max. height in (9.0)
→ Add seat support = NSH – max. height
= .... – .... = _____ (enter in 9.5)

☐ If RSH < ASH, then compare RTH to ATH.

RTH = ATH —Y→ Add NBC base support = ASH – RSH = ... – .... = _____ (enter in 9.4)

Add footrest = ASH – RSH = ... – .... = _____ (enter in 9.6)

N

RTH > ATH —Y→ Add NBC base support = (ASH - RSH) + (RTH - ATH) = (......... – ....) + (......... – ....) = _____ (enter in 9.4)

Add footrest = ASH – RSH = ... – .... = _____ (enter in 9.6)

N

Set NRTH = RTH + (ASH - RSH) = ... + (......... – ....) = _____. Then, compare NRTH to ATH.

NRTH = ATH —Y→ Add footrest = ASH – RSH = ... + ... = _____ (enter in 9.6)

N

NRTH > ATH —Y→ Add NBC base support = NRTH – ATH = ... – .... = _____ (enter in 9.4)

Add footrest = ASH – RSH = ... + ... = _____ (enter in 9.6)

N

Add seat support = ATH – NRTH = ... – .... = _____

Add footrest = (ATH – NRTH) + (ASH – RSH) = (....... – ....) + (....... – ....) = _____ (enter in 9.6)

Step 9: Summary of Recommended Adjustments

9.0 Adjust seat height to _____ cm.

9.1 Rec. NBC base angle: _____°

9.2 Rec. NBC screen angle: _____°

9.3 Rec. body-NBC distance: _____ cm.

9.4 Rec. NBC base support height: _____ cm.

9.5 Rec. seat support height: _____ cm.

9.6 Rec. footrest height: _____ cm.

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Figure 3. Final worksheet for female notebook computer (NBC) users. *Notes.* RSH = recommended seat height, ASH = actual seat height, RTH = recommended table height, ATH = actual table height, NRTH = new recommended table height.

4. NUMERICAL EXAMPLES

The following two numerical examples show how the worksheet can be used to compute the recommended adjustments.

4.1. Example 1

4.1.1. Input data

User:
  gender: female
  body height: 162 cm
NBC:
  screen size: 13.3"
Workstation:
  ATH: 72 cm
  ASH: 40 cm (fixed)

4.1.2. Computation of recommended adjustments

From the given body height (162 cm) and NBC screen size (13.3") and using the worksheet for female NBC users:

Step 1: recommended NBC base angle is 21° (enter in 9.1)

Step 2: recommended NBC screen angle is 121° (enter in 9.2)

Step 3: recommended body–NBC distance is 29 cm (enter in 9.3)

Step 4: RTH is 74 cm

Step 5: RSH is 42 cm

Step 6: since seat height is fixed, step 6 is skipped

Step 7: since RSH (42 cm) is higher than ASH (40 cm), the first flow chart in step 7 is used. Next, compare RTH to ATH. Since RTH (74 cm) is higher than ATH (72 cm), the recommended adjustments are as follows:

NBC base support = RTH − ATH = 74 − 72 = 2 cm (enter in 9.4)
seat support = RSH − ATH = 42 − 40 = 2 cm

Step 8: since the seat height is not adjustable, enter the seat support (from step 7) in (9.5)

Step 9: recommended adjustments can be summarized as follows:

set NBC base angle at 21°
set NBC screen angle at 121°
set body–NBC distance at 29 cm
use NBC base support with its height of 2 cm
use seat support with its height of 2 cm

Note that there are no recommended values in (9.0) and (9.6) in this example.

4.2. Example 2

4.2.1. Input data

User:
  gender: male
  body height: 170 cm
NBC:
  screen size: 15.4"
Workstation:
  ATH: 75 cm
  ASH: 46 cm (adjustable)
  min. height: 38 cm
  max. height: 48 cm

4.2.2. Computation of recommended adjustments

From the given body height (170 cm) and NBC screen size (15.4") and using the worksheet for male NBC users:

Step 1: recommended NBC base angle is 17° (enter in 9.1)

Step 2: recommended NBC screen angle is 117° (enter in 9.2)

Step 3: recommended body–NBC distance is 26 cm (enter in 9.3)

Step 4: RTH is 75 cm

Step 5: RSH is 46 cm

Step 6: since RSH (46 cm) is between the minimum (38 cm) and maximum (48 cm) height, then set ASH = RSH = 46 cm

Step 7: since RSH (46 cm) equals ASH (46 cm, from step 6), the second flow chart in step 7 is used. Next, compare RTH to ATH. Since RTH (75 cm) equals ATH (75 cm), no adjustments are required

Step 8: since the seat height is adjustable, then set NSH = ASH (from step 6) + seat support (from step 7) = 46 + 0 = 46 cm; since NSH (46 cm) is between the minimum (38 cm) and maximum (48 cm) height, enter NSH in (9.0)

Step 9: recommended adjustments can be summarized as follows:

adjust seat height to 46 cm
set NBC base angle at 17°
set NBC screen angle at 117°
set the body–NBC distance at 26 cm

Note that in this example, NBC base support, seat support, and footrest are not required.

5. EVALUATION OF THE RECOMMENDED ADJUSTMENTS

To evaluate the effectiveness of the worksheets in providing valid recommended adjustments, four volunteers (two males and two females) were seated at two workstations. Table 6 summarizes the data on the subjects, NBCs, and the workstations. Note that the seat height at both workstations was fixed.

Based on their body height, NBCs, and workstation height, the NBC and workstation adjustments were computed from (a) PostureAdjuster, (b) worksheets (see Tables 7–8). Figure 4 shows the subjects' seated postures based on

TABLE 6. Data on Subjects, Notebook Computers (NBCs), and Workstations

Subject				Workstation Height (cm)	
ID	Gender	Body Height (cm)	NBC Screen Size (")	Table	Seat
M1	male	181	14	80	46
M2	male	171	12.1	72	41
F1	female	152	12.1	80	46
F2	female	172	14	72	41

TABLE 7. Recommended Adjustments From Posture Adjuster

	NBC Adjustment			Workstation Adjustment (cm)		
Subject	Base Angle (°)	Screen Angle (°)	Distance (cm)	BS	SS	FR
M1	20	120	28	8	4	—
M2	24	124	30	10	5	—
F1	22	122	25	—	4	12
F2	22	122	28	8	4	—

Notes. NBC = notebook computer, distance = distance between body and NBC; BS = NBC base support; SS = seat support; FR = footrest.

TABLE 8. Recommended Adjustments From Worksheets

	NBC Adjustment			Workstation Adjustment (cm)		
Subject	Base Angle (°)	Screen Angle (°)	Distance (cm)	BS	SS	FR
M1	21	121	28	9	4	—
M2	24	124	30	9	5	—
F1	22	122	25	—	5	13
F2	22	122	29	8	4	—

Notes. NBC = notebook computer, distance = distance between body and NBC; BS = NBC base support; SS = seat support; FR = footrest.

the recommended adjustments from Posture Adjuster and the worksheets.

Readers can see that both PostureAdjuster and worksheets recommended using the same adjustment accessories for each subject. Furthermore, the adjustment settings in Tables 7–8 are remarkably close. The seated postures in Figure 4 also confirm that using the adjustment accessories as recommended can help to prevent awkward neck, back, shoulder, and wrist deviations usually observed in NBC users.

6. DISCUSSION

The NBC and workstation adjustment worksheets make it practical for NBC users to compute recommended NBC and workstation adjustments that can help them to sit with the appropriate seated posture when using NBCs. Unlike Posture Adjuster, which requires a computer to execute the program, the worksheets require a pencil only. For those NBC users who are not mathematically inclined, a basic calculator can be used as a computation tool.

The design of the worksheets emphasizes functionality, practicality, and usability. They must generate valid recommendations, can be used easily even without a calculator, and require minor training on how to use them. Initially, Posture Adjuster is used to generate recommended NBC adjustments, namely, NBC base angle, screen angle, and body–NBC distance. The adjustment settings are then tabulated according to the body height range and NBC screen size. In this process, some values might have to be adjusted to fit the combined body height range and NBC screen size. Additionally, the adjustment settings are rounded to the nearest integer. Readers should be aware that these modifications of adjustment settings can cause possible deviations from the recommendations generated by PostureAdjuster.

The workstation adjustments depend on the comparison between the ideal (recommended) and actual workstation height (i.e., table height and seat height). PostureAdjuster is used to generate recommended workstation height for NBC users with different body height and for NBCs with various screen sizes. The differences
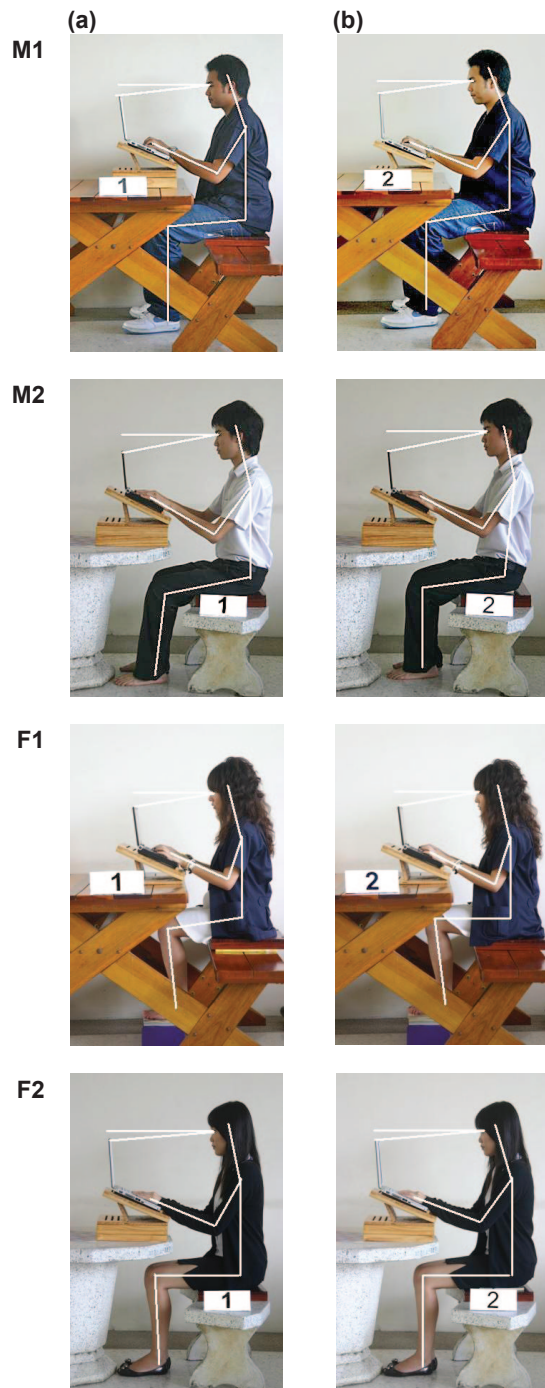

Figure 4. Comparison of seated postures: (a) PostureAdjuster, (b) adjustment worksheets.
Notes. M1, M2, F1, F2 = subjects' ID, see Table 6.

between the recommended and actual workstation height then indicate necessary adjustment accessories and their settings. The worksheets have three flow charts to help NBC users to compute the recommended adjustments. Depending on RSH and ASH, NBC users can select the

appropriate flow chart and easily follow its computation steps to obtain the results.

For simplicity and practicality, the computation procedure consists of nine sequential steps. In each step, the recommended adjustment is either forwarded to the next step or to the last step to be summarized. NBC users will be guided through the nine steps to make sure that the recommended adjustments are correctly computed. With some training and practice, NBC users can learn how to use the worksheets effectively.

The effectiveness of the worksheets was clearly demonstrated when the worksheets were used to compute the recommended NBC and workstation adjustments for four subjects. The subjects used different NBCs at two different workstations. For each subject, both PostureAdjuster and the worksheets were used separately. Tables 7–8 show that both approaches recommended the same adjustment accessories, with the maximum difference in adjustment settings of either 1 cm or 1°. In most cases, the recommended adjustment settings were identical. The comparison of seated postures in Figure 4 shows that the worksheets are as effective as PostureAdjuster in helping the subjects to sit with the appropriate seated posture when using NBCs. There are no awkward bends at the neck, shoulder, wrist, and back. Using the worksheet, a trained user can compute all necessary adjustment settings in under 2 min.

The worksheets consider only five NBC screen sizes, namely, 11.1", 12.1", 13.3", 14", and 15.4". For NBCs with other screen sizes, the screen size among the given five sizes that is closest to the actual screen size may be used instead. For the worksheet for male NBC users, the minimum and maximum body height is 155 and 185 cm, respectively. Male NBC users who are a little shorter than 155 cm can use 155 cm as their body height. Similarly, male NBC users who are a little taller than 185 cm can use 185 cm as their body height. In the same fashion, female NBC users who are a little shorter than 145 cm or a little taller than 175 cm can use the appropriate lower or upper values. However, if the user is much higher or much lower, the recommended adjustments might not be accurate.

Both PostureAdjuster and the worksheets were developed with selected anthropometric data of the Thai population, expressed as a function of body height. For NBC users of different nationalities, the anthropometric data are undeniably different. However, it is believed that the relationship between those data and body height might still be relatively similar. As such, the worksheets should be applicable for those NBC users as well. Readers should also realize that the recommended adjustments are merely estimated values. They should be considered as initial, rather than final, settings. The NBC and workstation adjustment accessories should be initially set at the given settings, and later fine-tuned as necessary.

The inherent ergonomics-related risk of NBCs gives rise to the recommendation of using an external keyboard and monitor in conjunction with NBCs. It should be noted that the use of an external keyboard and monitor is practical if the NBC is used at the user's personal workstation (either in an office or at home). It is unlikely that NBC users will carry either, along with the NBC, to different workplaces. On the other hand, portable and adjustable (height and/or angle) NBC stands are commercially available at affordable prices. At a minimum, NBC users who tend to use their NBCs at various places should bring an adjustable NBC stand and adjust its settings according to the adjustment settings recommended by the worksheet.

7. CONCLUSION

This paper discusses the design and construction of the NBC and workstation adjustment worksheets. The worksheets can be used to help male and female NBC users to compute the recommended adjustments so that they can set the NBC and workstation to allow them to sit appropriately when using NBCs. The worksheets are simple, practical, and effective. They do not require intensive training or any complex computation tool to compute the adjustment settings. On each worksheet, tables and flow charts are constructed to guide the user through all computation steps. Within a couple of minutes, the user can successfully compute the

recommended adjustments for the NBC and workstation.

There is no doubt that the worksheets are an effective tool to help NBC users to sit with the appropriate seated posture. With the number of NBC users increasing rapidly, more people will be at high risk of musculoskeletal disorders if they do not sit appropriately when using NBCs. Thus, the worksheets can significantly help to improve their safety.

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