Validity and Usability of Adjustment Worksheets for Computing Notebook Computer and Workstation Adjustments

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Abstract

The adjustment worksheets for computing notebook computer (NBC) and workstation adjustments is a successor of PostureAdjuster, a computerized tool for recommending necessary adjustments to help NBC users to sit with an appropriate seated posture during NBC operation. The adjustment worksheets contain tables and flow charts that enable NBC users to compute recommended adjustments based on the user's gender, body (stature) height, NBC size, work surface height, and seat height. In this paper, the validity and usability of the adjustment worksheets are analytically and experimentally investigated. The results show that the adjustment worksheets are as effective as PostureAdjuster in providing valid recommendations for the NBC and workstation adjustments. Due to its simple layout design and step-by-step computation procedure, NBC users can learn to use the adjustment worksheets to compute the NBC and workstation adjustments easily and quickly.

Keywords: Notebook computer, seated posture, usability, validity, office ergonomics

1. Introduction

Musculoskeletal problems such as neck and shoulder discomforts are common among office employees especially those who use a computer on a regular basis [1]. Discomfort is one of the symptoms at the first stage [2]. If the discomfort symptom is ignored, it can progress to severe pain or chronic disability which has impacts on rehabilitation services, lost work time, poor work quality, low work performance, decreased motivation, and stress from sickness [3]. The musculoskeletal discomfort is the result of various workrelated factors. 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 the musculoskeletal discomfort [4]. The discomfort can also be intensified by work situations, including physical demands at work, work organization, and psychological stress and depression from work [5].

Physical implications of notebook computer (NBC) operation on body posture have been reported [6, 7, 8, 9]. Straker et al. [8] presented a comparison of body postures during desktop computer and NBC operations. The results revealed that in terms of postural constraints and discomfort, desktop computer users felt better even after 20 minutes of computer use. Horikawa [10] 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. Straker et al. [11] suggested that NBC users would assume a posture 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. Harbison and Forrester [6] also found that NBC users require an increased forward head inclination to adequately operate the NBC due to its lack of adjustability. In their study, all NBC users adopted the neck flexion of more than 30° greater than the neck posture recommended in the Australian Standard 3590.2-1990, Screen-based workstations - Part 3: Input devices [12]. Sommerick et al. [13] 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, computer mouse, and numeric keypads. The results showed that in the stand-alone condition, the body postures are more deviated from the neutral positions. They concluded that the use of external peripheral devices can reduce stress on the neck.

Limited information about ergonomic recommendations is available for office employees who work with NBC [14]. Because of its hinge design, the heights of the NBC base and screen units cannot be independently adjusted. This design could lead to awkward work postures with excessive stresses at the neck and shoulder regions. Jalil and Nanthavanij [15] developed two analytical algorithms, with and without workstation constraints, for computing recommended adjustments such as footrest height, seat support height, NBC base support height, etc., so that an appropriate work posture during NBC operation can be obtained. Jamjumrus and Nanthavanij [16] also used the Jalil and Nanthavanij's adjustment algorithm with workstation constraints as an ergonomic intervention tool to improve the NBC users' work postures. They used the Rapid Upper Limb Assessment (RULA) technique to evaluate the work postures both before and after ergonomic intervention. Based on the RULA grand scores, a significant improvement in work posture was found.

Jalil and Nanthavanij [17] developed a computer program called PostureAdjuster to provide practical recommendations for adjusting the NBC and workstation to avoid awkward work postures during NBC operation. Posture Adjuster is based on the anthropometric data of the Thai population [18]. It is capable of performing three functions: (1) evaluating the current work posture, (2) generating practical adjustment recommendations, and (3) performing a work posture analysis by RULA. Nanthavanij et al. [19] later designed and constructed the adjustment worksheets for computing NBC and workstation adjustments without the need for a computer to execute PostureAdjuster to generate the solutions. Owing to the adjustment worksheets' simple layout design, NBC users can follow a step-by-step procedure to obtain the recommended adjustments for the NBC and workstation.

In this study, the validity of the adjustment worksheets was analytically investigated. Initially, a hypothetical set of data, which consists of the user's gender, body (stature) height, NBC size, and workstation surface heights, was developed. From this data set, both PostureAdjuster and the adjustment worksheets were used to obtain the recommended adjustments for the NBC and workstation. The results were then statistically compared. Both adjustment tools were also experimentally tested on several male and female university students who are NBC users. To investigate the usability, the adjustment worksheets were tested on a group of university students. After completing the training session, they were given hypothetical cases in which they were required to compute the recommended adjustments. Estimation times and correctness of results were then evaluated.

2. NBC and Workstation Adjustments

Adapted from the general recommendations given in the ANSI/HFS 100-1988 Standard [20], Jalil and Nanthavanij [15] recommended the appropriate work posture during NBC operation as described below.

1. The NBC user should sit with the back at an upright (or slightly reclined, if a backrest is provided) position.
2. Neck flexion should not exceed 10°.
3. Shoulder flexion should not exceed 20°.
4. Elbow flexion should be approxi mately 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 a right angle (90°) with the upper legs.
7. Both feet should rest comfortably on the floor (or on a footrest).
8. The viewing distance should be between 38 and 62 cm.

In the following sections, two adjustment tools for computing the NBC and workstation adjustments are explained.

2.1 PostureAdjuster Program

PostureAdjuster is a computerized tool that is designed to provide practical and easy-to-implement adjustment recommendations which include NBC base angle, screen angle, body-NBC distant, work surface height, and seat height. Additionally, there might be recommendations about seat support height, NBC base support height, and footrest height. These recommendations can effectively serve as an initial adjustment solution. If necessary, additional minor re-adjustments could be performed by NBC users. PostureAdjuster can generate a graphical display of the seated posture. It also allows the program users to download a picture of the NBC user's work posture for viewing during the analysis of work posture by the Rapid Upper Limb Assessment (RULA) technique.

PostureAdjuster requires three sets of input data, namely, the NBC user's anthropometric data, NBC dimensions, and workstation dimensions. NBC users can choose to enter the required anthropometric data directly. Alternatively, they can let PostureAdjuster estimate the data from the NBC user's body height by utilizing the anthropometric database of the Thai population [18].

Similarly, PostureAdjuster needs to know the following three physical dimensions of the NBC:

1. Distance from the front edge of the base unit to the keyboard's home row

2. Distance between the front and rear edges of the base unit

3. Distance between the top and bottom edges of the screen unit

NBC users can choose among three options to enter the NBC dimensions: (1) they can enter the information directly, (2) they can search in a built-in NBC database for a specific NBC brand and model, and (3) they can let PostureAdjuster estimate them from the known NBC screen size (in inch).

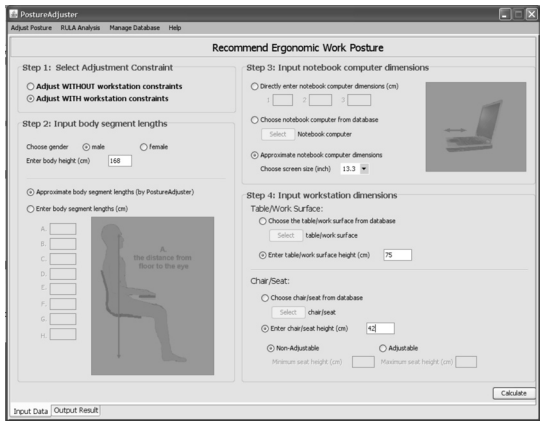
As for the workstation, PostureAdjuster requires two workstation dimensions, namely, work surface height (measured from the floor to the top surface of the workstation) and seat height. If the seat height is adjustable, both its minimum and minimum heights are also required. NBC users can choose either to enter the information directly or search in a built-in workstation database for the type of work surface and chair that they have.

PostureAdjuster uses two analytical algorithms to compute the recommended adjustments. Initially, the first algorithm is used to determine the (x, y) co-ordinates of all reference points and body joint angles to obtain the appropriate work posture by relaxing all workstation constraints. From the known co-ordinates, it is possible to derive the recommended (ideal) heights of the NBC and workstations, including the NBC base angle, screen angle, and user's body-NBC distance. Then, it compares between the recommended (ideal) and given (actual) work surface and seat heights, and recommends necessary adjustment accessories (e.g., NBC base support, seat support, and footrest) and their settings.

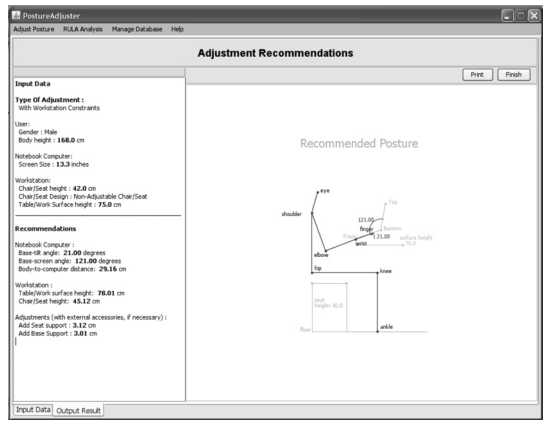
The outputs of PostureAdjuster consist of two sets of recommended adjustments, one set for the NBC and the other for the workstation. For the NBC, the recommended adjustments include: (1) NBC base angle, (2) screen angle, and (1) distance between the user's body and NBC. For the workstation, the recommended adjustments include: (1) NBC base support height, (2) seat support height, and (3) footrest height.

Fig. 1 shows the input and output screens of PostureAdjuster. In the output screen, a stick figure of the user's body is also presented to allow the program user to visualize the resulting seated posture.

For detailed discussion on PostureAdjuster, see Jalil and Nanthavanij [17].



(a) Input screen



(b) Output screen

Fig. 1. Snapshots of the input and output screens of PostureAdjuster.

2.2 Adjustment Worksheets

The adjustment worksheets make it practical for NBC users to compute recommended NBC and workstation adjustments any place, anywhere, and any time. Unlike PostureAdjuster, the adjustment worksheets do not require a computer to perform the computations. NBC users can compute the recommended adjustments by themselves. For those users who are not mathematically inclined, a basic calculator can be used to perform additions and subtractions.

The adjustment worksheets require the input data that are the same as those for PostureAdjuster. They include:

- User: Body height
- NBC: Screen size
- Workstation: Table height Seat height

Similarly, if the chair seat height is adjustable, both its minimum and maximum heights are required.

The computation procedure consists of nine steps

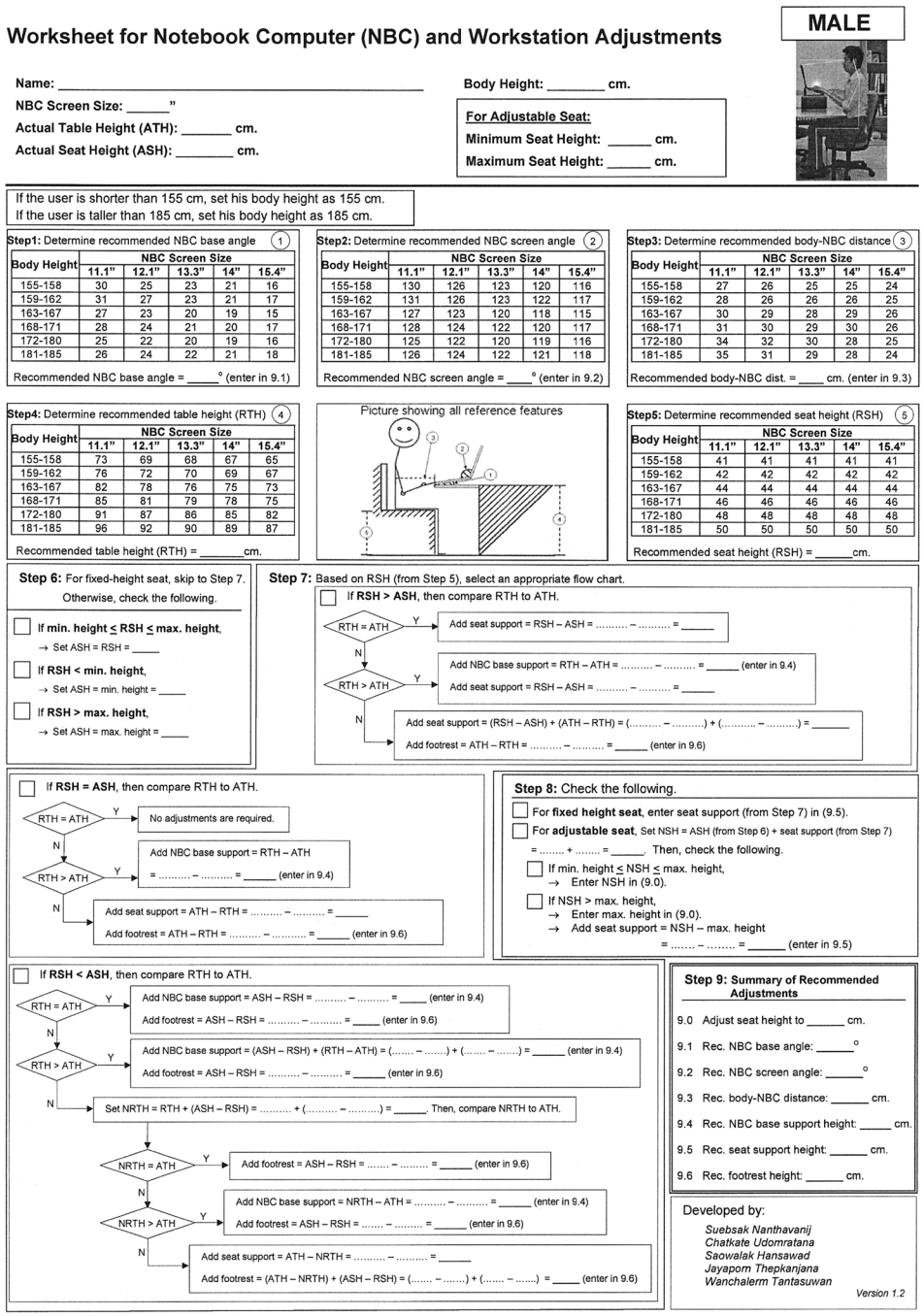
- Step 1: Determine the recommended NBC base angle
- Step 2: Determine the recommended NBC screen angle
- Step 3: Determine the recommended user's body-NBC distance
- Step 4: Determine the recommended table height
- Step 5: Determine the recommended seat height
- Step 6: Adjust the seat height (for adjustable chair)
- Step 7: Determine the recommended adjustments
- Step 8: Re-consider the use of seat support
- Step 9: Summarize the recommended adjustments

Initially, the adjustment worksheets need PostureAdjuster to generate the recommended NBC base angle, screen angle, user's body NBC distance, table height, and seat height. The adjustment settings are then tabulated according to the body height range and the NBC screen size. They are rounded to the nearest integer and some values have to be adjusted to fit the combined body height range and NBC screen size. In the first five steps, the user will only read the values from the appropriate tables.

In Step 6, the actual seat height should be set at the recommended seat height if possible. Otherwise, it should be set either at the minimum height or at the maximum height where appropriate. In Step 7, there are three flow charts to help to compute the recommended adjustments. Which flow chart is to be used depends on the comparison between the recommended and actual seat heights. In Step 8, the use of seat support will be re-considered. For example, if the sum of the actual seat height and seat support height is still between the minimum and maximum seat heights, seat support modification is not necessary. In Step 9, the recommended adjustments from Step 1 to Step 8 are summarized as follows:

- Seat height adjustment (for adjustable chair)
- Recommended NBC base angle
- Recommended NBC screen angle
- Recommended user's body-NBC distance
- Recommended NBC base support height
- Recommended seat support height
- Recommended footrest height

For detailed explanation on the computation procedure, see Nanthavanij et al. [19]. The adjustment worksheets for male and female NBC users are shown in Figs. 2 and 3, respectively. Readers can see that the adjustment worksheets contain blank spaces where the user can fill in the chosen or computed values in all nine steps.



Worksheet for Notebook Computer (NBC) and Workstation Adjustments

MALE

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 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)

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)

☐ 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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Version 1.2

Fig. 2. The adjustment worksheet for male NBC users [19]

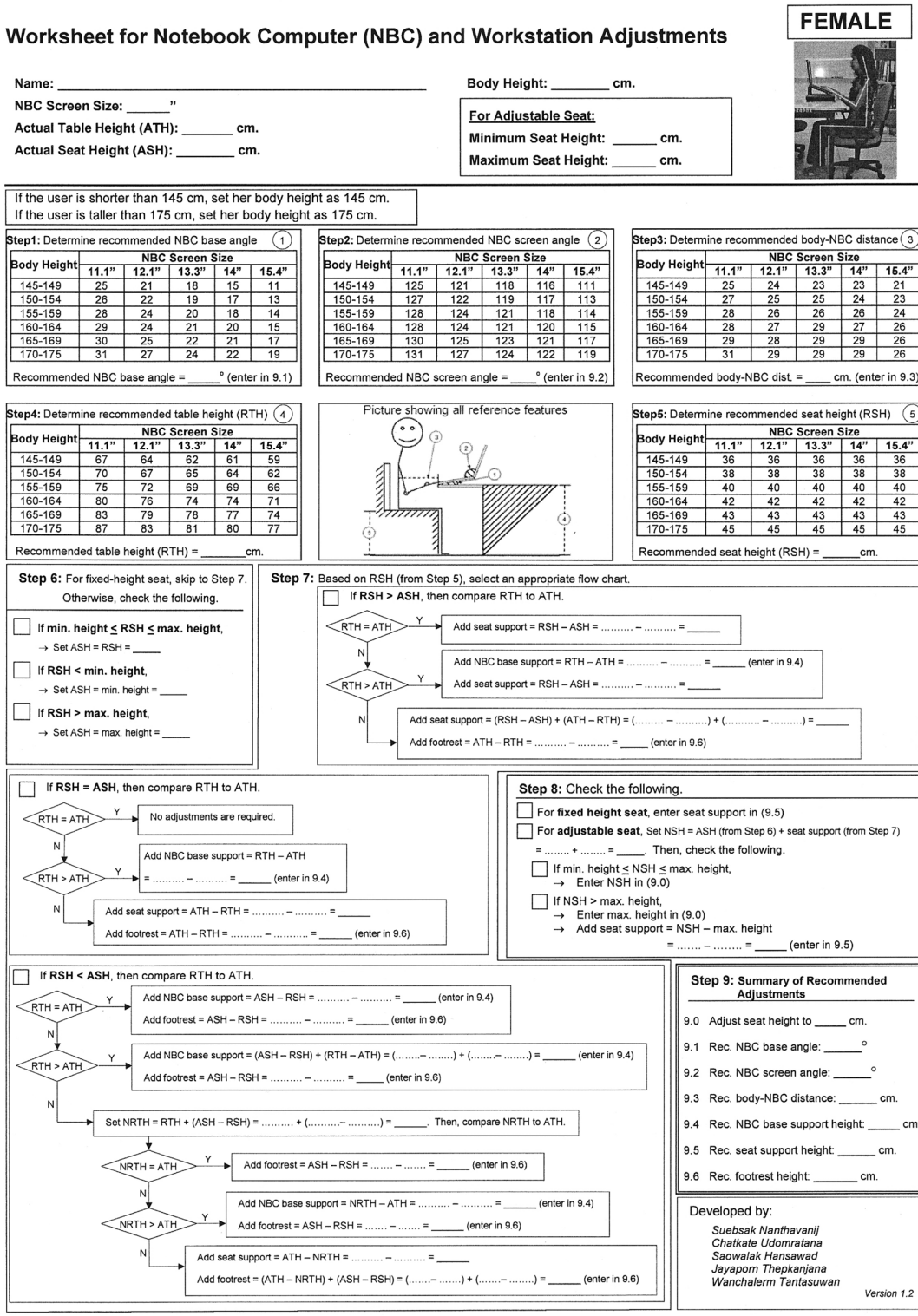


Fig. 3. The adjustment worksheet for female NBC users [19]

3. Validity of The Adjustment Work sheets

The adjustment worksheets are considered to give valid recommendations if the computed adjustment settings do not significantly differ from those generated by PostureAdjuster. In this study, two validity tests were conducted. The first test was analytical since it used a set of hypothetical data. The second test involved an investigation that was conducted on a group of volunteer university students. In both tests, both PostureAdjuster and the adjustment worksheets were used to compute the recommended adjustments

3.1 Analytical Test

Thirty test data for male NBC users and thirty test data for female NBC users were randomly generated. Each data consisted of the user's body height, NBC screen size, and workstation surface heights (table height and seat height). Table 1 shows the hypothetical test data used in the analytical validity test.

Table 1. Test data for the validity test.

Male NBC User					Female NBC Use				
ID	BH[1]	NBC[2]	TH[3]	SH[4]	ID	BH[1]	NBC[2]	TH[3]	SH[4]
AM1	153	13.3	74	41	AF1	143	13.3	74	41
AM2	155	11.1	72	45	AF2	145	11.1	72	4
AM3	156	14.0	75	47	AF3	146	14.0	75	47
AM4	157	12.1	70	46	AF4	147	12.1	70	46
AM5	158	11.1	76	49	AF5	148	11.1	76	49
AM6	159	13.3	73	42	AF6	149	13.3	73	42
AM7	160	15.4	77	48	AF7	150	15.4	77	48
AM8	161	12.1	71	40	AF8	151	12.1	71	40
AM9	162	14.0	78	50	AF9	152	14.0	78	50
AM10	163	11.1	79	42	AF10	153	11.1	79	42
AM11	164	15.4	75	41	AF11	154	15.4	75	41
AM12	165	13.3	80	40	AF12	155	13.3	80	40
AM13	166	12.1	72	47	AF13	156	12.1	72	47
AM14	167	15.4	70	45	AF14	157	15.4	70	45
AM15	168	14.0	78	49	AF15	158	14.0	78	49
AM16	169	15.4	74	50	AF16	159	15.4	74	50
AM17	170	13.3	71	46	AF17	160	13.3	71	46
AM18	171	11.1	76	48	AF18	161	11.1	76	48
AM19	172	14.0	73	43	AF19	162	14.0	73	43
AM20	173	12.1	77	44	AF20	163	12.1	77	44
AM21	174	15.4	80	42	AF21	164	15.4	80	42
AM22	175	14.0	75	44	AF22	165	14.0	75	44
AM23	176	11.1	70	49	AF23	166	11.1	70	49
AM24	177	13.3	79	45	AF24	167	13.3	79	45
AM25	178	12.1	72	48	AF25	168	12.1	72	48
AM26	179	14.0	77	40	AF26	169	14.0	77	40
AM27	180	11.1	73	46	AF27	170	11.1	73	46
AM28	181	15.4	71	41	AF28	171	15.4	71	41
AM29	185	12.1	74	43	AF29	175	12.1	74	43
AM30	187	13.3	76	47	AF30	177	13.3	76	47

[1]BH = Body height (cm); [2]NBC = NBC screen size (inch)
[3]TH = Table height (cm); [4]SH = Seat height (cm)

Tables 2 and 3 show the recommended adjustments for the hypothetical "male" and "female" NBC users, respectively. They were computed according to the assumed NBCs and workstations. Readers should also note that the computed adjustment settings obtained from PostureAdjuster were rounded to the nearest integer.

Table 2. Recommended adjustments for male NBC users.

ID	PostureAdjuster						Adjustment Worksheets					
	NBC			Workstation			NBC			Workstation		
	BA[1]	SA[2]	B-N[3]	BS[4]	SS[5]	FR[6]	BA[1]	SA[2]	B-N[3]	BS[4]	SS[5]	FR[6]
AM1	22	122	24	-	7	8	23	123	25	-	6	6
AM2	29	130	27	5	-	5	30	130	27	5	-	4
AM3	20	120	25	-	2	9	21	120	25	-	2	8
AM4	26	126	25	5	-	5	25	126	26	4	-	5
AM5	30	130	27	6	-	8	30	130	27	5	-	8
AM6	23	123	26	-	3	4	23	123	26	-	3	3
AM7	17	117	25	-	4	10	17	117	25	-	4	10
AM8	27	127	26	1	2	-	27	126	26	1	2	-
AM9	22	122	26	-	-	8	21	122	26	-	1	9
AM10	27	127	30	2	2	-	27	127	30	3	2	-
AM11	15	115	26	-	6	3	15	115	26	-	5	2
AM12	20	120	28	-	8	4	20	120	28	-	8	4
AM13	23	123	29	9	-	2	23	123	29	9	-	3
AM14	16	116	26	4	-	-	15	115	26	4	-	1
AM15	19	119	30	3	-	4	20	120	30	3	-	3
AM16	17	117	26	6	-	5	17	117	26	5	-	4
AM17	21	122	29	8	-	-	21	122	29	8	-	-
AM18	29	129	31	12	-	2	28	128	31	11	-	2
AM19	18	118	28	9	4	-	19	119	28	12	5	-
AM20	21	121	32	9	4	-	22	122	32	10	4	-
AM21	16	116	25	1	6	-	16	116	25	2	6	-
AM22	19	119	28	9	4	-	19	119	28	10	4	-
AM23	25	125	34	2 2	-	1	25	125	34	22	-	1
AM24	20	120	30	7	4	-	20	120	30	7	3	-
AM25	22	122	32	17	1	-	22	122	32	15	-	-
AM26	20	120	28	10	9	-	19	119	28	8	8	-
AM27	25	125	35	21	4	-	25	125	34	18	2	-
AM28	17	118	25	14	9	-	18	118	24	16	9	-
AM29	24	124	31	19	8	-	24	124	31	18	7	-
AM30	23	123	29	17	5	-	22	122	29	14	3	-

[1]BA = NBC base angle (degree); [2]SA = NBC screen angle (degree); [3]B-N = Body-NBC distance (cm)
[4]BS = NBC base support height (cm); [5]SS = Seat support height (cm); [6]FR = Footrest height (cm)

Table 3. Recommended adjustments for female NBC users.

ID	PostureAdjuster						Adjustment Worksheets					
	NBC			Workstation			NBC			Workstation		
	BA[1]	SA[2]	B-N[3]	BS[4]	SS[5]	FR[6]	BA[1]	SA[2]	B-N[3]	BS[4]	SS[5]	FR[6]
AF1	17	117	22	-	8	14	18	118	23	-	7	12
AF2	25	125	25	3	-	10	25	125	25	4	-	9
AF3	15	115	23	-	3	14	15	116	23	-3	1	4
AF4	21	121	24	4	-	10	21	121	24	4	-	10
AF5	26	126	25	5	-	13	25	125	25	4	-	13
AF6	18	118	24	-	4	10	18	118	23	-	5	11
AF7	12	112	22	-	5	16	13	113	23	-	5	15
AF8	22	122	25	-	1	32	21	222	5	-	2	4
AF9	18	117	24	-	-	12	17	117	24	-	2	14
AF10	27	127	27	-	3	7	26	127	27	-	5	9
AF11	13	113	24	-	8	10	13	113	23	-	10	13
AF12	20	120	25	-	11	12	20	121	26	-	11	11
AF13	23	123	26	6	-	8	24	124	26	7	-	7
AF14	14	114	24	2	-	5	14	114	24	1	-	5
AF15	19	118	26	1	-	9	18	118	26	-	-	9
AF16	15	114	25	4	-	10	14	114	24	2	-	10
AF17	21	121	26	7	-	4	21	121	29	7	-	4
AF18	28	128	28	9	-	6	29	128	28	10	-	6
AF19	20	120	27	2	-	1	20	120	27	2	-	1
AF20	24	125	27	1	-	2	24	124	27	1	-	2
AF21	16	116	26	-	8	7	15	115	26	-	9	9
AF22	20	120	27	2	-	1	21	121	29	3	-	1
AF23	30	129	29	19	-	6	30	130	29	19	-	6
AF24	23	123	27	-	-	2	22	123	29	1	-	2
AF25	26	126	28	13	-	4	25	125	28	12	-	5
AF26	21	121	28	1	4	-	21	121	29	-	3	-
AF27	30	130	30	14	-	2	31	131	31	15	-	1
AF28	18	118	26	5	4	-	19	119	26	6	4	-
AF29	27	127	29	10	3	-	27	127	29	9	2	-
AF30	24	124	30	8	-	1	24	124	29	7	-	2

[1]BA = NBC base angle (degree); [2]SA = NBC screen angle (degree); [3]B-N = Body-NBC distance (cm)
[4]BS = NBC base support height (cm); [5]SS = Seat support height (cm); [6]FR = Footrest height (cm)

The differences between individual adjustment settings computed from PostureAdjuster and the adjustment worksheets were statistically analyzed using a two-sided paired t-test with a level of difference (α) of 0.05. Table 4 presents t-statistic values of each pair of recommended adjustments. It is seen that for male NBC users, the differences between the values computed from PostureAdjuster and the adjustment worksheets are not statistically significant in five recommended adjustments. Only the difference in the seat support heights is slightly significant. For female NBC users, all differences are not significant. Thus, it can be concluded that the adjustment worksheets are satisfactorily effective in computing the recommended adjustments for both male and female NBC users.

Table 4. Summary of the paired t-statistic and critical t* values.

Recommended	Male NBC User			Female NBC User		
Adjustment	t-statistic	Significant?	p-value	t-statistic	Significant?	p-value
NBC base angle	-0.27	No	> 0.25	-0.84	No	> 0.10
NBC screen angle	0.33	No	> 0.40	-1.41	No	> 0.05
Body-NBC distance	0.00	No	> 0.40	-1.61	No	> 0.05
NBC base support height	0.86	No	> 0.15	0.47	No	> 0.25
Seat support height	2.11	Yes	< 0.025	-1.44	No	> 0.05
Footrest height	1.41	No	> 0.05	-1.03	No	> 0.10

Note: Level of significance (α) = 0.05; $|t^*| = 2.05$

3.2 Experimental Test

Twelve university students who were NBC users volunteered to participate in an experiment to validate the recommended adjustments computed using the adjustment worksheet. Six subjects were male and the other six were female. All subjects used their own NBCs, which had different sizes, in the experiment.

The subjects were randomly assigned to sit at one of the two workstations shown in Fig. 4. The workstations and their dimensions are as follows:

1. Wooden Workstation: Workstation surface height 80 cm
   Seat height 46 cm
2. Terrazzo Workstation: Workstation surface height 72 cm
   Seat height 41 cm

(Both workstations had fixed seat height.)

Table 5 presents the summary of the experimental test data.

(a) Wooden workstation (b) Terrazzo workstation

Fig. 4. Two NBC workstations used in the experimental test.

Table 5. The subjects' body heights, NBCs, and workstations.

Subject			NBC	Workstation		
ID	Gender	BH (cm)	Screen Size (inch)	Type	TH (cm)	SH (cm)
EM1	Male	181	14.0	Wooden	80	46
EM2	Male	172	15.4	Wooden	80	46
EM3	Male	192	13.3	Wooden	80	46
EM4	Male	174	14.0	Terrazzo	72	41
EM5	Male	181	14.0	Terrazzo	72	41
EM6	Male	171	12.1	Terrazzo	72	41
EF1	Female	152	12.1	Wooden	80	46
EF2	Female	165	15.4	Wooden	80	46
EF3	Female	168	15.4	Wooden	80	46
EF4	Female	156	11.1	Terrazzo	72	41
EF5	Female	165	15.4	Terrazzo	72	41
EF6	Female	172	14.0	Terrazzo	72	41

Note: BH = Body height; TH = Table height; SH = Seat height

From the subjects' body heights, NBC screen sizes, and workstation surface heights, the recommended adjustment settings were computed using PostureAdjuster and the adjustment worksheets. The mobile accessories were used to adjust both NBC and workstation. For more details on the mobile accessories, see Nanthavanij et al. [21].

Figs. 5 and 6 show seated postures of the male and female subjects, respectively. In all twelve subjects, it can be clearly seen that the postures labeled with No. 1 (PostureAdjuster) look almost identical to those labeled with No. 2 (adjustment adjustment worksheets). The subjects' seated postures also look natural and in compliance with the guidelines given in Section 2. No awkward neck, shoulder, wrist, and back deviations are observed in those seated postures.

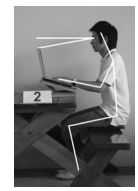
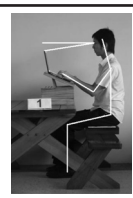
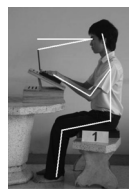
PostureAdjuster	Adjustment Worksheets
NBC: Base angle: 20° Screen angle: 120° Body-NBC distance: 28 cm Workstation: Base support: 8 cm Seat support: 4 cm Footrest: n/a 	NBC: Base angle: 21° Screen angle: 121° Body-NBC distance: 28 cm Workstation: Base support: 9 cm Seat support: 4 cm Footrest: n/a 
Subject EM1	
NBC: Base angle: 15° Screen angle: 115° Body-NBC distance: 25 cm Workstation: Base support: n/a Seat support: 1 cm Footrest: n/a 	NBC: Base angle: 16° Screen angle: 116° Body-NBC distance: 25 cm Workstation: Base support: 2 cm Seat support: 2 cm Footrest: n/a 
Subject EM2	
NBC: Base angle: 24° Screen angle: 124° Body-NBC distance: 29 cm Workstation: Base support: 16 cm Seat support: 7 cm Footrest: n/a 	NBC: Base angle: 22° Screen angle: 122° Body-NBC distance: 29 cm Workstation: Base support: 10 cm Seat support: 4 cm Footrest: n/a 
Subject EM3	
NBC: Base angle: 19° Screen angle: 118° Body-NBC distance: 28 cm Workstation: Base support: 12 cm Seat support: 7 cm Footrest: n/a 	NBC: Base angle: 19° Screen angle: 119° Body-NBC distance: 28 cm Workstation: Base support: 13 cm Seat support: 7 cm Footrest: n/a 
Subject EM4	
NBC: Base angle: 20° Screen angle: 120° Body-NBC distance: 28 cm Workstation: Base support: 16 cm Seat support: 9 cm Footrest: n/a 	NBC: Base angle: 21° Screen angle: 121° Body-NBC distance: 28 cm Workstation: Base support: 17 cm Seat support: 9 cm Footrest: n/a 
Subject EM5	
NBC: Base angle: 24° Screen angle: 124° Body-NBC distance: 30 cm Workstation: Base support: 7 cm Seat support: 5 cm Footrest: n/a 	NBC: Base angle: 24° Screen angle: 124° Body-NBC distance: 30 cm Workstation: Base support: 9 cm Seat support: 5 cm Footrest: n/a 
Subject EM6	

Fig. 5. Seated postures of male subjects.

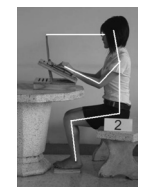
PostureAdjuster	Adjustment Worksheets
NBC: Base angle: 22° Screen angle: 122° Body-NBC distance: 25 cm Workstation: Base support: n/a Seat support: 4 cm Footrest: 12 cm 	NBC: Base angle: 22° Screen angle: 122° Body-NBC distance: 25 cm Workstation: Base support: n/a Seat support: 5 cm Footrest: 13 cm 
Subject EF1	
NBC: Base angle: 16° Screen angle: 116° Body-NBC distance: 26 cm Workstation: Base support: n/a Seat support: 4 cm Footrest: 7 cm 	NBC: Base angle: 17° Screen angle: 117° Body-NBC distance: 26 cm Workstation: Base support: n/a Seat support: 3 cm Footrest: 6 cm 
Subject EF2	
NBC: Base angle: 17° Screen angle: 117° Body-NBC distance: 26 cm Workstation: Base support: n/a Seat support: 3 cm Footrest: 5 cm 	NBC: Base angle: 17° Screen angle: 117° Body-NBC distance: 26 cm Workstation: Base support: n/a Seat support: 3 cm Footrest: 6 cm 
Subject EF3	
NBC: Base angle: 27° Screen angle: 127° Body-NBC distance: 28 cm Workstation: Base support: 4 cm Seat support: n/a Footrest: 2 cm 	NBC: Base angle: 28° Screen angle: 128° Body-NBC distance: 28 cm Workstation: Base support: 4 cm Seat support: n/a Footrest: 1 cm 
Subject EF4	
NBC: Base angle: 16° Screen angle: 116° Body-NBC distance: 26 cm Workstation: Base support: 1 cm Seat support: 2 cm Footrest: n/a 	NBC: Base angle: 17° Screen angle: 117° Body-NBC distance: 26 cm Workstation: Base support: 2 cm Seat support: 2 cm Footrest: n/a 
Subject EF5	
NBC: Base angle: 22° Screen angle: 122° Body-NBC distance: 28 cm Workstation: Base support: 8 cm Seat support: 4 cm Footrest: n/a 	NBC: Base angle: 22° Screen angle: 122° Body-NBC distance: 29 cm Workstation: Base support: 8 cm Seat support: 4 cm Footrest: n/a 
Subject EF6	

Fig. 6. Seated postures of female subjects.8

4. Usability of The Adjustment Work sheets

Fifteen subjects voluntarily participated in an experiment to investigate the usability of the adjustment worksheets. All of them were university students and they were NBC users. Among them, eight subjects were male and the other seven subjects were female. While the subjects were of Thai nationality, they were studying in an international program in which English is a medium of instruction. Additionally, all of them were engineering management major. Therefore, they could understand the flow charts and the computation logic reasonably well.

The subjects were trained how to use the adjustment worksheets to compute the recommended adjustments. The training was conducted in their native language (i.e., Thai) to maximize their understanding. Firstly, the subjects were explained about the appropriate seated posture during NBC use. Then, they were explained about the adjustment worksheets and how to use them.

Two hypothetical examples were used in the training session. The first example involved an NBC workstation with a fixed chair, while the second example used an adjustable chair. The subjects were explained in detail how to obtain the recommended NBC adjustments from the tables and how to compute the recommended workstation adjustments using the flow charts. The training session lasted about 20 minutes.

Next, the subjects were given two test problems and were asked to use the adjustment worksheets to compute the recommended NBC and workstation adjustments. The data of the two test problems are as follows:

Test Problem 1:

NBC user:	Female
	Body height = 163 cm
NBC:	Screen size = 13.3"
Workstation:	Work surface height = 73 cm
	Seat height = 46 cm (fixed)

Test Problem 2:

NBC user:	Male
	Body height = 176 cm
NBC:	Screen size = 12.1"
Workstation:	Work surface height = 76 cm
	Seat height = 45 cm (adjustable)
	- Minimum height = 40 cm
	- Maximum height = 50 cm

The subjects' computed results for both test problems were then compared to the solutions. For test problem 1, an average time to compute all adjustment settings was 2.56 minutes, with a standard deviation of 0.22 minute. Among the fifteen subjects, only the first subject made a small mistake in obtaining the recommended adjustment settings. In fact, it was an error in reading a value from one table. For test problem 2, the average computation time was 3.36 minutes, with the standard deviation of 0.12 minute. All subjects could obtain the correct adjustment settings. Test problem 2 involved an adjustable chair and required more computation steps than test problem 1 (when the fixed chair was assumed), This could explain why all subjects spent more time on test problem 2 than on test problem 1. Table 6 summarizes the results of the usability test.

With short computation time and near-perfect score, it is reasonable to conclude that the adjustment worksheets are simple to use and NBC users can obtain the correct NBC and workstation adjustments easily and quickly.

Table 6. Results of the usability experiment

Subject		Test Problem 1		Test Problem 2	
ID	Gender	Time (min)	Correctness	Time (min)	Correctness
UM1	Male	2.37	No	3.25	Yes
UM2	Male	2.50	Yes	3.18	Yes
UM3	Male	3.14	Yes	3.52	Yes
UM4	Male	2.61	Yes	3.34	Yes
UM5	Male	2.40	Yes	3.31	Yes
UM6	Male	2.57	Yes	3.47	Yes
UM7	Male	2.75	Yes	3.52	Yes
UM8	Male	2.54	Yes	3.22	Yes
UF1	Female	2.58	Yes	3.58	Yes
UF2	Female	2.44	Yes	3.27	Yes
UF3	Female	2.36	Yes	3.44	Yes
UF4	Female	2.86	Yes	3.37	Yes
UF5	Female	2.43	Yes	3.24	Yes
UF6	Female	2.38	Yes	3.36	Yes
UF7	Female	2.41	Yes	3.28	Yes

5. Discussion

In the validity experiment, the recommended adjustments obtained from PostureAdjuster were used as the benchmark results. The computed results from the adjustment worksheets are considered valid if they are the same or not significantly different from those benchmark settings. The validity experiment was divided into two parts: (1) analytical test, and (2) experimental test.

In the analytical test, two sets of hypothetical data were randomly generated. The first data set represents 30 hypothetical male NBC users and the second data set represents 30 hypothetical female NBC users. Most body heights were within the applicable ranges of the adjustment worksheets (i.e., 145-175 cm for female users and 155-185 cm for male users). Some hypothetical

NBC users were assumed to be either shorter or taller than the bounds of body heights in the adjustment worksheets. It is seen that in most cases, the adjustment worksheets could give the recommended adjustments which were exactly the same as the benchmark solutions. The maximum deviation observed in Tables 2 and 3 is 3 cm (footrest height). The differences in the recommended adjustments computed between PostureAdjuster and the adjustment worksheets were statistically insignificant, expect for the difference in the seat support height of male NBC users. Nevertheless, such difference should not clinically make any difference since in real practice NBC users can make additional adjustment by themselves to obtain their most comfortable work posture.

There are three contributing causes of the deviations found in the results from the adjustment worksheets. The first possible cause is the error caused by grouping and modifying the values generated by PostureAdjuster to fit in the pre-defined body height ranges and NBC sizes. For example, consider the body height range of 155-159 cm. and NBC size of 13.3″ of the female adjustment worksheet. Using PostureAdjuster, there would have been five values for the NBC base angle. However, only the NBC base angle of 21° is used to represent the NBC base angle of this body height range. During an attempt to simplify the table, either the mean or the mode is used as a representative setting.

The second cause is the rounding error. In order to enhance its practicality, it makes no sense to recommend NBC users to adjust the NBC base angle to 23.55°, or to place it 26.43 cm away from the body. Thus, all adjustment settings generated by PostureAdjuster were rounded to the nearest integer when shown on the adjustment worksheets. If the decimal point is 0.01-0.49, the number would be rounded down. In the case of 0.50-0.99, the number would be rounded up. This could have caused a deviation of up to 2 cm or degrees.

The third cause is also the rounding error. When presenting the benchmark settings (as computed from PostureAdjuster), the same rounding logic was used.

In the experimental test, the subjects' seated postures were adjusted according to the results from PostureAdjuster and those from the adjustment worksheets without any changes. These settings were merely estimated values. While the results fit reasonably well for most subjects, some subjects might need additional small adjustments. This can explain why, for some subjects, the knee joint angle does not look quite right (see Figs. 5 and 6). In practice, these recommendations should be considered as initial adjustments, not the final ones.

For the subject EM3 whose body height is 192 cm, the adjustment worksheet for male NBC users gave results which were quite different from the benchmark values. This is because his body height exceeds the maximum body height that the adjustment worksheet can accommodate (which is only 185 cm). As suggested by the procedure, all settings for this subject were computed by assuming that his body height was 185 cm. In general, this approach can perhaps obtain the settings that are close to the benchmark values if the actual body height is not that much different from the upper bound value. With the difference of 7 cm (i.e., 192–185 = 7 cm), it should not be surprising to see large deviations. Nevertheless, the subject's seated posture still looks acceptable even when the recommended adjustments computed from the adjustment worksheet for male NBC users were applied.

The usability investigation involved fifteen volunteer university students who were required to use the adjustment worksheets to compute the recommended adjustments. After finishing the 20-minute training session, they were given two test problems. Only one subject made a small error in reading one value from the table. This clearly shows that with some training, the subjects can acquire enough knowledge to use the adjustment worksheets by themselves. The average times for computing the adjustment settings were 2.56 minutes and 3.36 minutes for test problem 1 and test problem 2, respectively. The computation times were also quite uniform among the fifteen subjects. It is believed that with frequent usage, the computation time could be reduced by half.

Test problem 2 required longer computation time than test problem 1. This delay was expected since the chair in test problem 2 was assumed to be an adjustable chair. More computation steps were required to obtain the recommended adjustments.

6. Conclusion

The adjustment worksheets (one for male NBC users and the other for female NBC users) are simple to use and can yield recommended adjustments which are satisfactorily close to those from its predecessor, PostureAdjuster. Within just a few minutes, NBC users will be able to compute the recommended adjustments by following the steps shown on the adjustment worksheets. The results from the adjustment worksheets are as effective as those from PostureAdjuster in helping NBC users to assume the appropriate seated posture. Although the adjustment worksheets are based on the anthropometric data of the Thai population, it is expected that they would also be applicable to NBC users of other nationalities since the body part dimensions are expressed as percentages of body height. In practice, the recommended adjustments computed from the adjustment worksheet should be considered as initial settings. For some NBC users, they might need to adjust the NBC and workstation (and the accessories) a little more after implementing the recommendations.

Without using adjustment accessories and setting them at the right settings, it is very difficult, if not impossible, for NBC users to sit and operate their NBC with the appropriate seated posture. This is due to the fact that the use of NBC would cause the neck and shoulder postures to be compromised. If the NBC screen is positioned such that the user's neck posture is appropriate, the upper arm must be raised to reach the keyboard that is too high, causing the shoulder and wrist to flex excessively. On the other hand, if the keyboard is ergonomically positioned at the elbow height, the wrist posture will be correct but the neck must be flexed excessively to view the screen that is too low. NBC users must also be aware that the so called appropriate seated posture can still induce musculoskeletal discomforts especially when the NBC operation is prolonged. Frequent rest breaks are strongly recommended.

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