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EFFECTS OF BODY HEIGHT, NOTEBOOK COMPUTER SIZE, AND WORKSTATION HEIGHT ON RECOMMENDED ADJUSTMENTS FOR PROPER WORK POSTURE WHEN OPERATING A NOTEBOOK COMPUTER

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Factors which are likely to affect recommended workstation and notebook computer (NBC) adjustments to obtain ergonomic work posture during NBC operation are investigated. They are: (1) body height, (2) NBC size, and (3) workstation height (i.e., seat and work surface heights). Six recommended adjustments which are evaluated include: (1) footrest height, (2) seat support height, (3) NBC base support height, (4) distance between the user's body and NBC (or user-NBC distance), (5) tilt angle of NBC base, and (6) screen angle. It is found that body height has a significant effect on footrest height and user-NBC distance while NBC size has a significant effect on user-NBC distance, tilt angle of NBC base, and screen angle. Workstation height, on the other hand, does not show any effect on the six recommended adjustments. However, the results suggest that there are interactions between body height and NBC size, and between body height and workstation height when evaluating their effects on footrest height, tilt angle of NBC base, and screen angle.
Key words: Notebook computer operation; workstation; seated posture; notebook computer settings; workstation adjustments

INTRODUCTION

Owing to their light weight, small size, portability, and battery power option, notebook computers (NBCs) have quickly become very popular among computer users. NBCs are available in various sizes as defined by their screen size (measured in the same way as that of a television set). Unlike conventional desktop computers, NBCs can be used under various work settings. It is not unusual to see people using NBCs at places such as classrooms, university libraries, university canteens, university center, internet coffee shops, airports, etc.

Prolonged visual display terminal (VDT) operation can lead to musculoskeletal disorders (MSD) and cumulative trauma disorders (CTD) such as low back pain, carpal tunnel syndrome (CTS), stiff shoulders, and sore neck. The problems are more intensified if work posture is awkward, e.g., the bent neck, bent wrists, or flexed/extended forearms. Numerous research studies were conducted to give recommendations about VDT (desktop computer) operation and seated posture, resulting in the ANSI/HFS 100-1988 Standard (The Human Factors Society, 1988). Unfortunately, the recommendations given in the standard apply only to the desktop computer use.

Because of its hinge design, the heights of NBC base and screen units cannot be independently adjusted. This design could lead to a work 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 the 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 pos-

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ture 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.

It is reasonable to suspect that NBC users' work posture is likely to be more awkward than that 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 the trapezius muscle increased.

Sommerick et al. (2002) conducted a detailed study to evaluate the effects of NBC on body posture when being operated in a stand-alone condition and with inexpensive ordinary peripheral input devices such as an external keyboard, a 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.

There are several recommendations and guidelines for workstation adjustments to obtain the correct work posture during VDT operation. In Nanthavanij and Venezia (1999), a computerized VDT workstation adjustment program called *IntelAd* was discussed in detail. The adjustment algorithm in *IntelAd* was based on two input data, namely, gender and body height. Its recommendations include VDT user's seat height, keyboard height, and monitor height. The effectiveness of *IntelAD* in providing valid adjustment recommendations was tested and confirmed in Nanthavanij (1996a). Nanthavanij (1996b) used the same adjustment algorithm to evaluate several types of VDT workstation and developed the body height-workstation settings matrix to assist VDT users in adjusting their workstation. Based on the *IntelAD*'s algorithm, Rurkhamet and Nanthavanij (2004a) later developed an analytical design method for computing workstation settings and positioning computer accessories so as to help VDT users sit with the correct posture. To computerize the computation procedure, Rurkhamet and Nanthavanij (2004b) developed a rule-based decision support system, called EQ-DeX, based on their analytical algorithm. The EQ-DeX provides quantitative adjustment recommendations and displays line figures to illustrate the resulting workstation settings and computer accessories layout.

When compared with the research studies on VDT (desktop computer) operation, the number of those on NBC operation is still small especially those concerning a quantitative approach. Jalil and Nanthavanij (2007) developed two analytical algorithms, with and without constraints, to give adjustment recommendations such as footrest height, seat support height, NBC base support height, etc. so that the correct work posture can be obtained while operating NBCs. Jamjumrus and Nanthavanij (2007) also used the Jalil and Nanthavanij's adjustment algorithm with workstation constraints as a tool for ergonomic intervention to improve the work posture of NBC users. They used the Rapid Upper Limb Assessment (RULA) technique to evaluate the work posture of NBC users before and after ergonomic intervention. The results showed that, from the RULA scores, significant improvement in work posture was found.

This research study is intended to investigate how body height, NBC size, and workstation height affect the recommended workstation and NBC adjustments. The adjustment algorithm with workstation constraints developed by Jalil and Nanthavanij (2007) is used as an analytical tool to recommend six recommended adjustments. The paper is organized as follows. Firstly, we explain the adjustment algorithms, including the input data and results (i.e., workstation and NBC adjustments).

Next, we describe the three factors which are investigated in this study, computational experiment, and relevant statistical analysis. Then, the effects of body height, NBC size, and workstation height on the recommended adjustments are reported and discussed. Finally, the conclusion is given.

ADJUSTMENT ALGORITHMS

Jalil and Nanthavanij (2007) developed two analytical algorithms to recommend workstation and NBC adjustments so that NBC users can assume the correct work posture during NBC operation. The required input data, algorithms, and results are briefly described in the following sections.

Input data

The adjustment algorithms require the following input data: (1) NBC user's body part dimensions, (2) NBC dimensions, and (3) workstation constraints (seat height and work surface height). The algorithms use anthropometric formulas to estimate the following body part dimensions from the user's body height and gender: (1) eye height (sitting), (2) shoulder height (sitting), (3) length of upper arm, (4) length of lower arm, (5) length of hand, (6) popliteal height (sitting), (7) length of upper leg, and (8) length of lower leg. From the estimated body part dimensions, selected body reference points are defined. They are: (1) eye, (2) shoulder joint, (3) elbow joint, (4) wrist joint, (5) fingertip at the middle finger, (6) hip joint, (7) knee joint, and (8) ankle joint.

It is also necessary to know three physical dimensions of NBC in order to define the coordinates of its reference points. The required dimensions can be estimated from the known NBC screen size. Firstly, these physical dimensions are determined (either from direct measurement or estimation): (1) distance between the front edge of NBC base and the keyboard's home row, (2) distance between the front and rear edges of NBC base, and (3) distance between the top and bottom edges of the NBC screen. Next, selected reference points of NBC are defined as follows: (1) keyboard's home row, (2) front edge of NBC base, (3) rear edge of NBC base, (4) bottom edge of NBC screen, and top edge of NBC screen.

In real workplaces, most NBC users normally sit on a chair and place their NBC on a table during NBC operation. Thus, two workstation constraints, namely, seat height and work surface height, must be considered to simulate real work settings. More specifically, they are pre-requisites for giving *realistic* adjustment recommendations.

Algorithms

In the first algorithm, it is assumed that there are no workstation constraints. That is, the algorithm freely positions the user's body and NBC to form the correct work posture for NBC operation. It also computes coordinates of selected body and NBC reference points, and body joint angles. This algorithm helps to determine the recommended adjustments to obtain the *ideal* (ergonomic) work posture. Figure 1 shows a flow chart of this algorithm.

The second algorithm considers two workstation constraints, namely, seat height and work surface height. It imports the recommended adjustments determined using the first algorithm, conceptually positions the user's body and NBC at the given workstation, and recommends workstation and NBC adjustments wherever necessary. Figure 2 shows a flow chart of the second algorithm. Additionally, a list of abbreviations shown in both Figures 1 and 2 is presented in Appendix 1. The nine conditions mentioned in Figure 2 are defined in Appendix 2.

For ease of use, the computations in both adjustment algorithms are computerized using the MATLAB program.

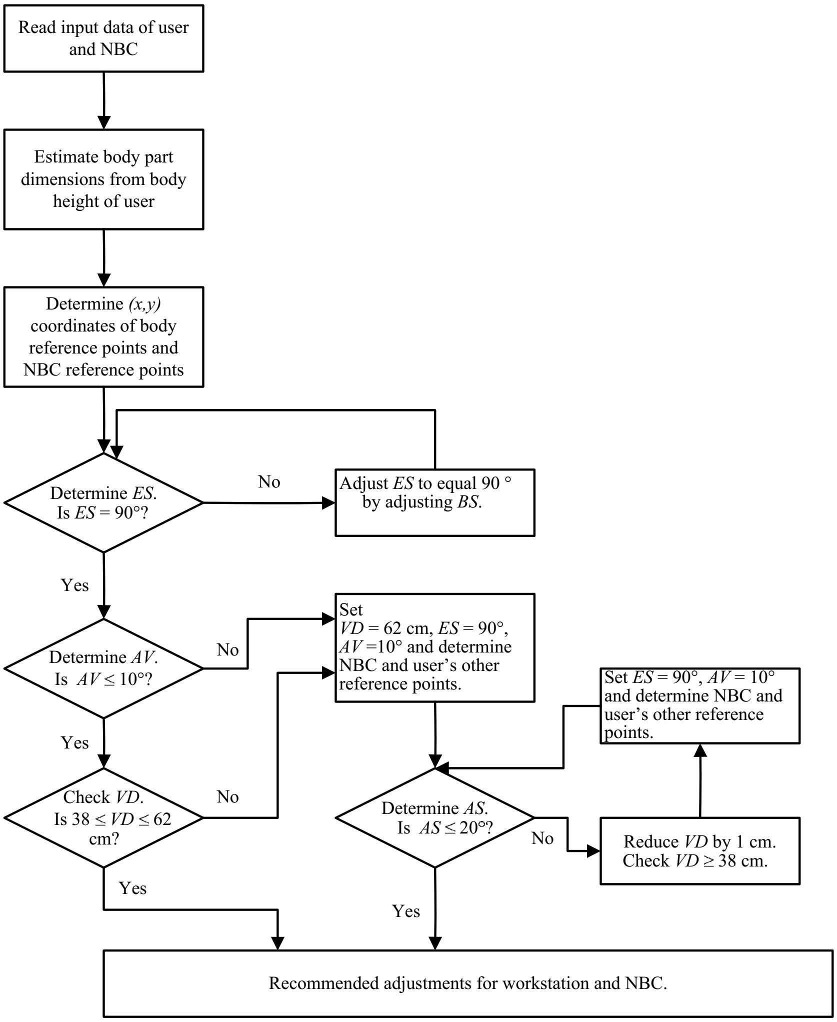


Fig. 1. Flow chart of the algorithm without workstation constraints (Jalil and Nanthavanij, 2007).

Results

The algorithms determine the required (x, y) coordinates of the user's body and NBC reference points, including body joint angles. However, providing such information to NBC users will be useless since they will not be able to measure their joint coordinates and angles. Thus, the results are translated into necessary workstation and NBC adjustments, from which the correct work posture can be assumed.

The recommended adjustments can be divided into two groups. The first group consists of three adjustments which belong to the workstation. They are: footrest height, seat support height, and NBC base support height. The second group consists of three adjustments for NBC. They are: user-NBC distance, tilt angle of NBC base, and screen angle. The six workstation and NBC adjustments are briefly summarized as follows.

1. Footrest: A platform (leveled or inclined) that is placed on the floor right underneath both feet to keep them from dangling.

2. Seat support: A seat cushion that is placed on a chair seat in order to raise the seat level height to reach a recommended level 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.

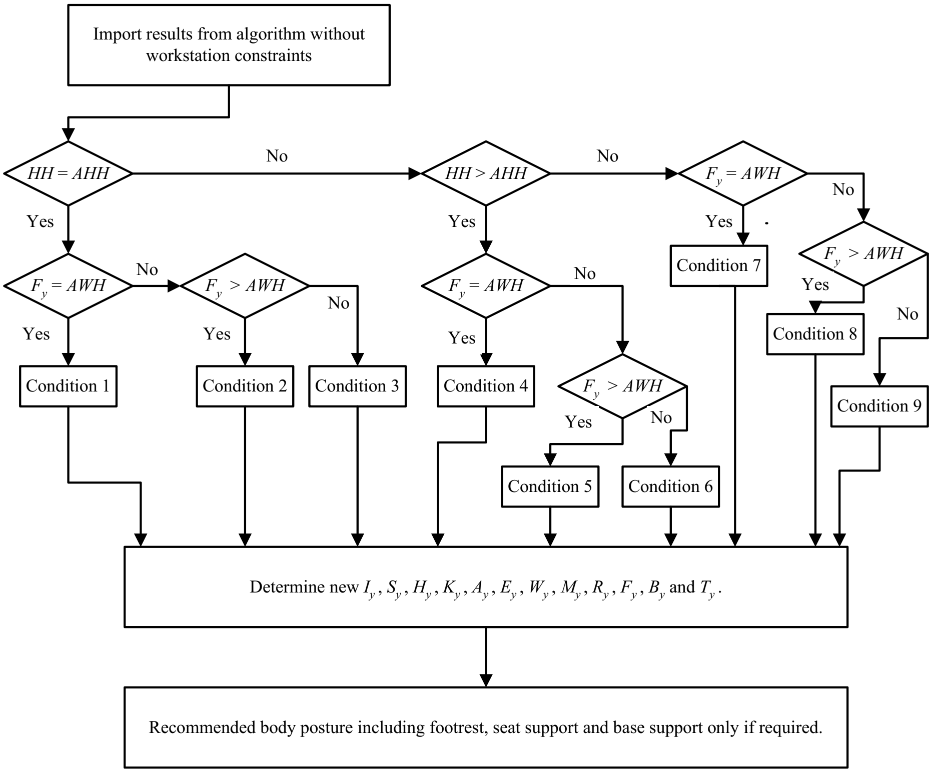


Fig. 2. Flow chart of the algorithm with workstation constraints (Jalil and Nanthavanij, 2007).

3. NBC base support: A leveled platform that is placed on the workstation right underneath the NBC in order to raise the level height of NBC so that the user can operate the keyboard and view the screen with the correct upper extremity posture (e.g., shoulder, elbow, wrist, and neck).

4. User-NBC distance: This distance represents a clearance between the user's body and NBC. It is measured horizontally from the front surface of trunk to the front edge of NBC base.

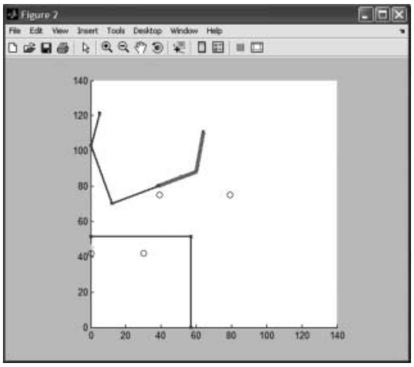
5. Tilt angle of NBC base: It is an angle between the surface of workstation (or NBC base support) and NBC base. For example, if the NBC is laid flat on the workstation (or NBC base support), its tilt angle is zero.

6. Screen angle: It is an angle between NBC base and its screen. When the NBC lid is closed, this angle is zero.

Figure 3 shows the recommended adjustments for a Thai male NBC user whose body height is 168 cm using a 13.3-inch NBC at a workstation where the seat height and work surface height are 42 and 75 cm, respectively. Note that all adjustments are rounded to the nearest integer for practicality.

The adjustment algorithm with workstation constraint is effective in helping the NBC user adjust one's workstation and NBC so that one can assume the correct work posture. As an example, the left photograph in Figure 4 shows a Thai female NBC user at her workstation. The user sits on a non-adjustable chair and places her NBC on a writing desk. Due to a mismatch between her body height and workstation, the user has to bend her trunk, neck, and both wrists excessively to view the screen and operate the keyboard. It is also seen that she uses the edge of the desk to support both lower arms, possibly causing excessive compression at the underneath.

The right photograph shows the work posture of the same NBC user at the same workstation after the workstation and NBC adjustments have been implemented. Readers can see a significant improvement in her work posture especially at the trunk, neck, and wrist. The recommended adjustments for this female NBC user are:



User:	Gender = male
	Body height = 168 cm
NBC:	13.3" screen size
Workstation:	Seat height = 42 cm
	Work surface height = 75 cm

Recommended Work Posture

Viewing angle:	10∞
Shoulder flexion:	20∞
Elbow flexion:	89∞
Wrist deviation:	0∞
Viewing distance:	60 cm
Seat height:	45 cm
Work surface height:	78 cm

Recommended Adjustments

Footrest height:	-
Seat support height:	3 cm
NBC base support height:	3 cm
Distance between body and NBC:	29 cm
NBC tilt angle:	21∞
Screen angle:	121∞

Fig. 3. Recommended adjustments from the algorithm with workstation constraints.

Fig. 4. NBC user's work postures, before (left) and after (right) adjustments.

Footrest height:	6 cm	(not seen in the photograph)
Seat support height:	- cm	
NBC base support height:	1 cm	
User – NBC distance:	26 cm	
NBC base tilt angle:	21°	
Screen angle:	121°	

FACTORS AFFECTING WORKSTATION AND NBC ADJUSTMENTS

Body height

As reported by Nanthavanij and Venezia (1998), Rurkhamet and Nanthavanij (2004a), and Rurkhamet and Nanthavanij (2004b), the required VDT workstation adjustments depend on the gender and body height of VDT users, which are used to estimate the body part dimensions. Nanthavanij (1996b) also showed that body height is one important factor that significantly affects the VDT workstation settings. It is thus reasonable to suspect that the workstation and NBC adjustments should be affected by the user's body height as well. Jalil and Nanthavanij (2007) developed six sets of formulas to estimate body part dimensions based on the most recent anthropometric database of Thai population (Thai Industrial Standards Institute, 2001). These formulas use body height as a predictor of body part dimensions. The six formulas are for male and female populations and three percentiles (5^{th}, 50^{th}, and 95^{th}) of body height.

In this research, two body height levels are investigated, namely, *short* and *tall*. Quantitatively, a Thai female with body height at the 5^{th} percentile is used to represent *short* body height. Based on the anthropometric database of Thai population, this body height is 146.4 cm. For *tall* body height, a Thai male whose body height is at the 95^{th} percentile is assumed to be the representative. Based on the same database, this body height is 177.1 cm.

From a known body height, the appropriate set of formulas is used to estimate key body part dimensions and to define coordinates of selected body and reference points.

NBC size

Unlike desktop computers, NBCs come in various sizes. The size of NBC is typically defined by its screen size. Conventionally, the NBC screen is measured diagonally and expressed in inches. It is also noted that the screen and base units of the NBC are of the same dimensions, both length and width. Therefore, the NBC that has a small screen tends to have a small keyboard area.

Five NBC sizes that are very popular among NBC users are:

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

The physical dimensions of the three NBC parts mentioned in Section 2.1 are determined for each NBC size. Table 1 shows the average dimensions of these three NBC parts for different NBC sizes.

In this research, we use the 11.1-inch NBC to represent *small* NBC and the 15-inch NBC to represent *large* NBC. The NBCs having the screen size which is smaller than 11.1 inches are expensive and difficult to operate due to a small keyboard area, making them unpopular. Those having the screen size which is larger than 15 inches (e.g., 17 inches) are too large and too heavy to be carried around; thus, they are not popular either.

Workstation height

One major advantage of NBC is its portability, which makes it easy to be brought along and used wherever needed. As such, it is rather difficult to define what the NBC workstation is. One may consider that the NBC workstation simply consists of a table where the NBC is placed on and a chair where the user sits. Specific seat height and work surface height of NBC workstation have never been defined in the literature since their variety is too large.

At a selected university in Thailand, two common places (workstations) where university stu-

Table 1. Average dimensions (in cm) of selected NBC parts.

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

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

dents use their NBCs are observed (see Figure 5). Their seat heights and work surface heights are measured and listed below.

1. Terrazzo table-and-chair set
   - Seat height: 40 cm
   - Work surface height: 68 cm
2. Wooden table-and-chair set
   - Seat height: 45 cm
   - Work surface height: 76 cm

For convenience, this research refers to the terrazzo table-and-chair set as a *low* workstation due to its low seat height (40 cm) and low work surface height (68 cm) and to the wooden table-and-chair set as a *high* workstation due to its high seat height (45 cm) and high work surface height (76 cm).

(a) Terrazzo table-and-chair set (b) Wooden table-and-chair set

Fig. 5. Two common places where the use of NBC is seen around the university campus.

DESIGN OF COMPUTATIONAL EXPERIMENT

In order to investigate how body height, NBC size, and workstation height described in the previous section significantly affect the recommended workstation and NBC adjustments, a 2^k-factorial experiment, where $k = 3$, is designed and carried out. For each factor, two factor levels are considered.

Factor A (*Body height*) - *Short height* (146.40 cm)
- *Tall height* (177.10 cm)

Factor B (*NBC size*) - *Small NBC* (11.1-inch screen)
- *Large NBC* (15-inch screen)

Factor C (*Workstation height*) - *Low workstation* (terrazzo table-and-chair set)
- *High workstation* (wooden table-and-chair set)

The adjustment algorithm with workstation constraints is run eight times with different factor level combinations to generate eight sets of recommended workstation and NBC adjustments. The following list shows the combination of factor levels for each of the eight experimental runs.

Test Combination 1 - *short body height – small NBC size – low workstation*
Test Combination 2 - *short body height – small NBC size – high workstation*
Test Combination 3 - *short body height – large NBC size – low workstation*
Test Combination 4 - *short body height – large NBC size – high workstation*
Test Combination 5 - *tall body height – small NBC size – low workstation*
Test Combination 6 - *tall body height – small NBC size – high workstation*

Test Combination 7 - *tall body height – large NBC size – low workstation*

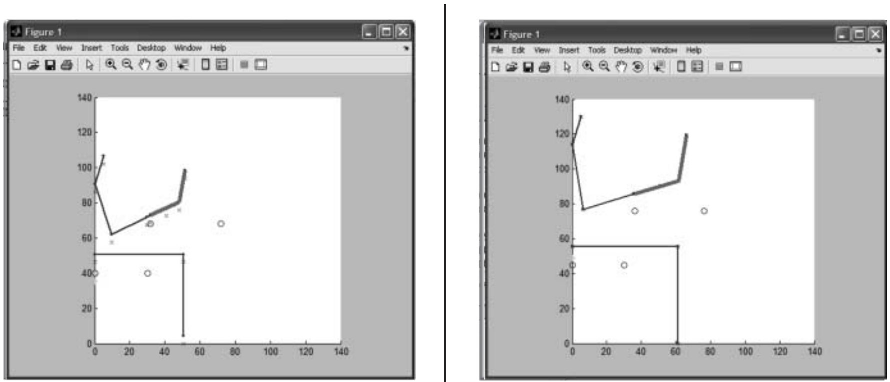
Test Combination 8 - *tall body height – large NBC size – high workstation*

For ease of understanding, the summary of the above 2^3-factorial "*workstation and NBC adjustment*" experiment is presented in Table 2. Figure 6 displays examples of two *extreme* test combinations, namely, Test Combination 1 and Test Combination 8. Note that the recommended workstation and NBC adjustments shown in italic are used in the statistical analysis.

Table 2. The workstation and NBC adjustments experiment.

Test combination	Coded factor A	Coded factor B	Coded factor C	Factor	Factor level Low (–1)	Factor level High (+1)
1	–1	–1	–1	A – Body Height	146.40 cm	177.10 cm
2	–1	–1	+1	B – NBC size (screen)	11.1-inch	15-inch
3	–1	+1	–1	C – Workstation height	SH = 40 cm	SH = 45 cm
4	–1	+1	+1		WH = 68 cm	WH = 76 cm
5	+1	–1	–1			
6	+1	–1	+1			
7	+1	+1	–1			
8	+1	+1	+1			

SH = seat height, WH = work surface height



Recommended Posture		Recommended Adjustments	
Viewing angle:	10∞	*Footrest height:*	*4 cm*
Shoulder flexion:	19∞	*Seat support height:*	-
Elbow flexion:	83∞	*NBC base support height:*	*3 cm*
Wrist deviation:	0∞	*Distance (body-NBC):*	*25 cm*
Viewing distance:	47 cm	*NBC tilt angle:*	*26∞*
Seat height:	36 cm	*Screen angle:*	*126∞*
Work surface height:	67 cm		
Test Combination 1		- *Short* body height - *Small* NBC size - *Low* workstation	

Recommended Posture		Recommended Adjustments	
Viewing angle:	10∞	*Footrest height:*	-
Shoulder flexion:	10∞	*Seat support height:*	*4 cm*
Elbow flexion:	83∞	*NBC base support height:*	*7 cm*
Wrist deviation:	0∞	*Distance (body-NBC):*	*25 cm*
Viewing distance:	62 cm	*NBC tilt angle:*	*17∞*
Seat height:	49 cm	*Screen angle:*	*117∞*
Work surface height:	83 cm		
Test Combination 8		- *Tall* body height - *Large* NBC size - *High* workstation	

Fig. 6. Results from test combination 1 (left) and test combination 8 (right).

RESULTS AND DISCUSSION

It should be noted that the experimental data are generated from the adjustment algorithm with workstation constraints developed by Jalil and Nanthavanij (2007), not from the actual experiment. When the same set of input data (i.e., body height, NBC size, and workstation dimensions) is used, the algorithm will always generate the same set of recommended adjustments. As a result, there is only one replicate in each test combination.

A drawback of an *unreplicated* factorial is that there is no internal estimate of error (or pure error). One approach to the analysis of the *unreplicated* factorial is to assume that certain high-order interactions are negligible and combine their mean squares to estimate the error. That is, it is assumed that the main effects and some low-order interactions dominate the system effects. However, this approach is appropriate only when high-order interactions are reasonably low and negligible (Montgomery, 2001).

From the analysis of the variance (ANOVA) table and the assumption that two-factor and three-factor interactions are negligible in all workstation and NBC adjustments, their mean squares are combined to represent the error mean square. The ANOVA table can then be modified and the *F* statistics of the three factors can be computed.

The reporting and discussion of the results is divided into two parts, the first part dealing with the workstation adjustments (footrest height, seat support height, and NBC base support height) and the second part dealing with the NBC adjustments (user – NBC distance, tilt angle of NBC base, and screen angle).

Workstation adjustments

Table 3 shows the summary of recommended workstation adjustments. Tables 4 to 6 show modified ANOVA tables for the effects on footrest height, seat support height, and NBC base support height, respectively. Note that it is not possible to draw any statistical conclusion on the interaction effects.

Table 3. Summary of recommended workstation adjustments.

Factor level			Recommended workstation adjustment (cm)		
Body height	NBC size	Workstation	Footrest	Seat support	NBC base support
Short (146.40 cm)	Small	Low	4	0	3
		High	10	0	0
	Large	Low	9	5	21
		High	17	8	0
Tall (177.10 cm)	Small	Low	0	9	24
		High	0	4	16
	Large	Low	0	9	15
		High	0	4	7

Table 4. ANOVA table for the effect on footrest height.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	200.00	1	200.00	18.38	$p < 0.025$
NBC size	18.00	1	18.00	1.65	No
Workstation height	24.50	1	24.50	2.25	No
Error	43.50	4	10.88		
Total	286.00	7			

Table 5. ANOVA table for the effect on seat support height.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	21.13	1	21.13	1.90	No
NBC size	21.13	1	21.13	1.90	No
Workstation height	6.13	1	6.13	0.55	No
Error	44.50	4	11.13		
Total	92.89	7			

Table 6. ANOVA table for the effect on NBC base support height.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	180.50	1	180.50	2.88	No
NBC size	0.00	1	0.00	0.00	No
Workstation height	200.00	1	200.00	3.19	No
Error	251.00	4	62.80		
Total	631.50	7			

1. Effect of body height

From the ANOVA tables, it is found that body height has a significant effect on footrest height, but does not affect seat support height and NBC base support height. When comparing the results between short and tall NBC users, it is seen that the short user needs to use footrest to prevent both feet from dangling while the tall user does not. For the seat support height and NBC base support height, the data shown in Table 3 seem to indicate that both short and tall NBC users need to use both seat support and NBC base support and the tall user is likely to use the supports that are higher than those used by the short user. However, there is not enough evidence to conclude accordingly.

2. Effect of NBC size

NBC size does not show any significant effect on the three workstation adjustments. However, the data in Table 3 seem to indicate that there might be an interaction effect between NBC size and body height on footrest height. The short user who uses small NBC seem to need footrest that is lower than the one needed when using large NBC. However, the tall user never needs footrest. No interaction effects between NBC size and the other two factors on seat support height and NBC base support height are suggested by the data.

3. Effect of workstation height

Similar to NBC size, workstation height does not show any significant effect on the three workstation adjustments. Once again, the data in Table 3 suggest that there exists an interaction effect between workstation height and body height on footrest height. For the short NBC user, the recommended footrest height increases with the height of workstation. For the tall NBC user, however, such relation is not seen.

From the above results, it is clear that only the effect of body height on footrest height is significant. However, the data suggest that there are some interaction effects between body height and NBC size and between body height and workstation height on footrest height. Unfortunately, the *unreplicated* factorial does not allow us to draw meaningful conclusions on the interaction effects.

The short NBC user needs to add footrest at the workstation irrespective of the size of NBC and height of workstation. This is to keep both feet from dangling. A higher footrest is also needed when the larger NBC or the higher workstation is used. The short user needs to place seat support on the chair seat only when large NBC is used. This is because the eye level height must be raised so that the user can view the screen conveniently. NBC base support is also needed in certain work settings in order to raise the level height of NBC keyboard so that the short user can work with the correct wrist posture.

The tall NBC user does not need footrest since both feet can rest comfortably on the floor. However, seat support is to be placed on the chair seat so that the user can sit with the right angle at both knee joints. It is also seen that the lower the seat height, the higher the seat support must be. When the tall user works with small NBC, high NBC base support is required to raise the keyboard height in order to maintain the correct wrist posture during NBC operation.

NBC adjustments

Table 7 shows the summary of the recommended NBC adjustments. Tables 8 to 10 show modified ANOVA tables for the effects on the three NBC adjustments, respectively. Note that the ANOVA tables for the tilt angle of NBC base and screen angle are identical.

Table 7. Summary of recommended NBC adjustments.

Factor level			Recommended NBC Adjustment		
Body height	NBC size	Workstation	Distance* (cm)	Tilt angle (∞)	Screen angle (∞)
Short (146.40 cm)	Small	Low	25	26	126
		High	26	26	126
	Large	Low	21	11	111
		High	21	11	111
Tall (177.10 cm)	Small	Low	34	25	125
		High	34	25	125
	Large	Low	26	17	117
		High	25	17	117

*User – NBC distance

Table 8. ANOVA table for the effect on user-NBC distance.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	84.50	1	84.50	37.56	$p < 0.005$
NBC size	84.50	1	84.50	37.56	$p < 0.005$
Workstation height	0.00	1	0.00	0.00	No
Error	9.00	4	2.25		
Total	178.00	7			

Table 9. ANOVA table for the effect on tilt angle of NBC base.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	12.50	1	12.50	2.04	No
NBC size	264.50	1	264.50	43.15	$p < 0.005$
Workstation height	0.00	1	0.00	0.00	No
Error	24.50	4	6.13		
Total	301.50	7			

Table 10. ANOVA table for the effect on screen angle.

Source of variation	Sum of squares	Degrees of freedom	Mean square	*F*	Significant
Body height	12.50	1	12.50	2.04	No
NBC size	264.50	1	264.50	43.15	$p < 0.005$
Workstation height	0.00	1	0.00	0.00	No
Error	24.50	4	6.13		
Total	301.50	7			

1. Effect of body height

From Tables 8 to 10, body height is found to have a significant effect only on the user-NBC distance. The data in Table 6 indicate that the distance between the user's body and NBC increases proportionally with body height. That is, the tall NBC user should place the NBC farther away from the body than the short user. This recommendation is reasonable since the tall user has long "elbow-finger tip" dimension and, thus, needs to position the NBC correspondingly.

For the tilt angle of NBC base, no significant effect of body height is found. However, a proportional increase in tilt angle of NBC base with body height is observed when the large NBC is used. For the small NBC, tilt angle remains relatively unchanged. Similar changes are also observed when evaluating screen angle. It is suspected that these findings can be partly explained by the dependence between the user-NBC distance and both the tilt and screen angles.

Basically, adjusting tilt angle of NBC base and screen angle is required in order to obtain the correct wrist and neck posture when operating the keyboard and viewing the screen. For any user, when the NBC is placed closed to the body, the screen angle must be large for proper viewing. On the other hand, when the NBC is positioned far from the body, the screen angle must be decreased. Such dependence could be strong enough for the small NBC to cause both tilt angle and screen angle to stay unchanged when the recommended user-NBC distance varies proportionally.

2. Effect of NBC size

NBC size is also found to be a significant factor for all three recommended NBC adjustments. When comparing between small and large NBCs operated by the same user, the data in Table 7 show that the small NBC should be placed farther away from the user's body than the large one. The main reason for this recommendation is perhaps due to the difference in the "front edge-home row" dimensions between the small and large NBCs. Since the smaller NBC also has a smaller "front edge-home row" dimension, it is reasonable to move the NBC farther away so that the user can maintain proper shoulder flexion, elbow flexion, and wrist posture.

The effect of NBC size on tilt angle is however negatively proportional. The tilt angle of NBC base of the small NBC is larger than that of the large one. It is also seen that when the tall NBC user uses the large NBC, the recommended tilt angle becomes large. It is believed that this recommendation is attributed to the viewing angle and incidence angle required for proper viewing of the screen.

When investigating the effect of NBC size on screen angle, the same pattern as that found on tilt angle is seen.

3. Effect of workstation height

It is of interest that workstation height does not cause any significant effect on all three recommended NBC adjustments. From the data shown in Table 7, readers can clearly see that the recommended adjustments are identical for both terrazzo and wooden table-and-chair sets. It is suspected that the small differences in seat heights and in work surface heights between the two NBC workstations used in this study might not be enough to cause any changes in the three NBC adjustments. To increase the differences in seat heights and in work surface heights so that the effects could be found will require the workstation heights which are not realistic.

From the above results, body height and NBC size are the two factors which have a significant effect on the recommended NBC adjustments. The effect of body height is significant on the user-NBC distance only, while the effect of NBC size is significant on all three NBC adjustments. Workstation height does not show any significant effect on any of the recommended adjustments.

The data also suggest that there is an interaction effect between body height and NBC size on both the tilt and screen angles. However, the analysis of the *unreplicated* factorial cannot reveal such interaction effect.

CONCLUSION

In this research, the effects of body height, NBC size, and workstation height on six recommended workstation and NBC adjustments are investigated. These adjustments include footrest height, seat support height, NBC base support height, user-NBC distance, tilt angle of NBC base, and screen angle. Based on the *unreplicated* 2^3-factorial design, a computational experiment is carried out. As a result, eight sets of recommended workstation and NBC adjustments are analytically obtained.

For the three workstation adjustments (i.e., footrest height, seat support height, and NBC base support height), it is found that only the effect of body height on footrest height is significant. The data also suggest that there are some interaction effects between body height and NBC size and between body height and workstation height on footrest height. The short NBC user needs to use footrest to support both feet. It is observed that the larger the size of NBC, the higher the footrest is. Similarly, when the higher workstation is used, the height of footrest also increases. The short NBC user needs to place seat support on the chair seat only when the large NBC is used. NBC base support is also required in some work settings. The tall NBC user does not need to use footrest at all. However, seat support is required in order to sit with the right angle at the knee joints. The lower the seat height, the higher the seat support must be. When working with the small NBC, the tall user requires high NBC base support.

For the three NBC adjustments (i.e., user-NBC distance, tilt angle of NBC base, and screen angle), it is found that body height has a significant effect on the user-NBC distance, while NBC size significantly affects all three NBC adjustments. No significant effect of workstation height on any NBC adjustment is found. The data also suggest that there is an interaction effect between body height and NBC size on both angles. Furthermore, it is suspected that tilt angle of NBC base and screen angle are dependent of the user-NBC distance.

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APPENDICES

Appendix 1: List of abbreviations

Ay	(*y*) co-ordinate of the ankle joint
AHH	actual seat height (cm)
AS	shoulder flexion angle (degree), measured between the upper and lower arms
AV	viewing angle (degree), measured between the horizontal line and the normal line of sight (at the screen top)
AWH	actual work surface height (cm)
B_y	(*y*) co-ordinate of the rear edge of the NBC base unit
BS	screen angle (degree), measured between the NBC base and screen units
E_y	(*y*) co-ordinate of the elbow joint
ES	incidence angle (degree), measured between the normal line of sight and the screen surface
F_y	(*y*) co-ordinate of the front edge of the NBC base unit
H_y	(*y*) co-ordinate of the hip joint
HH	recommended seat height (cm)
I_y	(*y*) co-ordinate of the *e*ye
K_y	(*y*) co-ordinate of the knee joint
M_y	(*y*) co-ordinate of the fingertip (of the middle finger)
R_y	(*y*) co-ordinate of the keyboard's home row
S_y	(*y*) co-ordinate of the shoulder joint
T_y	(*y*) co-ordinate of the top edge of the NBC screen unit
VD	viewing distance (cm)
W_y	(*y*) co-ordinate of the wrist joint

Appendix 2: List of 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: $HH < AHH, F_y < AWH$

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