COMPARISON OF WORK POSTURES DURING NOTEBOOK COMPUTER USE BETWEEN USER-PREFERRED AND RECOMMENDED WORKSTATION SETTINGS

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Abstract

This paper discusses an experiment that was conducted to evaluate the effectiveness of a computer program, called *ErgoNBC*, which provides suggestions regarding the adjustment settings of notebook computer (NBC), workstation components, and selected accessories in order to help computer users assume an appropriate work posture during NBC work. Twenty-four university students voluntarily participated in the experiment which includes three experimental trials. In the first trial, the subjects were allowed to set up the NBC and workstation freely. In the second trial, the NBC and workstation were set up according to the recommendations from *ErgoNBC*. In the last trial, the subjects were given an opportunity to re-adjust the recommended settings. The Rapid Upper Limb Assessment (RULA) technique was used to evaluate their work postures during the three trials. The results of the paired *t*-test clearly showed that *ErgoNBC* could significantly help to improve the subjects' work postures.

Keywords: Validation, Ergonomic work posture, Workstation settings, NBC settings

1. INTRODUCTION

In the era of digital information, notebook computers (NBCs) have become increasingly popular for business, educational, and personal use. Despite its popularity, a large number of users still do not know how to ergonomically adjust their NBC and workstation, resulting in various awkward work postures during NBC work. As such, the NBC users are likely to be confronted with musculoskeletal disorders (MSDs) (Wahlström, 2005).

Several research studies were performed to evaluate work postures, both qualitatively and quantitatively, of computer operators while working with the computer. Some studies also focused on the use of external accessories to adjust the work posture. Rempel et al. (2006) evaluated the effect of the workstation interventions among computer operators. They found that by providing a forearm support in conjunction with the ergonomic training, work postures were improved which could help to reduce upper body pain. Culig et al. (2008) revealed that using ergonomic workstations resulted in substantial improvements in safe posture during the performance management phase. Asundi et al. (2012) found that using the 12° inclined notebook support as a portable accessory significantly improved head and neck postures during NBC use on tables in portable environments.

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It is known that the visual display terminal (VDT) workstation and its proper adjustment are essential for helping computer users to assume correct work posture. Extensive research on these issues has been conducted especially for the desktop computer operation. Shikdar and Al-Kindi (2007) identified ergonomic deficiencies in VDT workstation design in typical offices by using questionnaires. They concluded that ergonomic deficiencies were significant in the physical design, component layout, and others, particularly of the computer workstation facilities and furniture, which may have contributed to ergonomic deficiencies in terms of layout and workstation adjustment. Design specifications for an ergonomic VDT workstation were discussed in detail in the ANSI/HFES 100-2007 Standard (HFES, 2007). Hsiao and Cho (2011) reported that even the standard desks and chairs that are designed for workplace can still cause constraints to computer users.

Regarding the NBC work, very few research results were reported when compared to those of desktop computer operation. Moreover, the use of workstation accessories such as footrest, seat cushion, and NBC base support (or platform) was rarely discussed. These accessories are generally required for NBC users when working at the workstation with limited adjustability. Jalil and Nanthavanij (2007) proposed analytical procedures for computing necessary NBC and workstation adjustments. However, they only considered one type of workstation, namely, non-adjustable (fixed) workstation. Jalil et al. (2007) later developed a Java-based computer program called *PostureAdjuster* that recommends adjustment settings for NBC and workstation based on their procedures. Nanthavanij et al. (2010) proposed manual worksheets for estimating NBC and workstation adjustment settings for NBC users. The worksheets also suggest, if necessary, the NBC base support, seat cushion, and footrest, including their settings, for needy NBC users. They also showed that the implementation of recommended adjustments is effective in helping to adjust work postures of NBC users. However, some quantitative analysis background and training are required to be able to use the manual worksheets correctly. Nanthavanij et al. (2013b) developed a software program called *ErgoNBC* that provides quantitative recommendations about how to set up the NBC, workstation, and accessories to obtain an appropriate work posture.

In this paper, an experiment to validate an effectiveness of *ErgoNBC* and its results are presented. The paper is organized as follows. Firstly, the experimental design is described. The subjects, equipment, and experimental procedure are explained. Furthermore, the design of *ErgoNBC* is briefly described. Next, its results are reported and discussed. Finally, the conclusion is given.

2. EXPERIMENT

2.1 Subjects

Twenty-four university students, twelve males and twelve females, participated in an experiment designed to validate the adjustment settings recommended by *ErgoNBC*. All subjects voluntarily agreed to take part in this experiment without receiving monetary compensation. They were informed about the purpose of the experiment and involved activities, and signed the informed consent. The subjects were regular users of NBC. None of the subjects ever had injuries at the neck, shoulders, wrists, and lower back in the past.

2.2 Equipment

2.2.1 Notebook Computers

Three NBCs were used in this experiment. Their screen sizes were 11", 13", and 15". They were standard NBCs and thus could be easily operated by the subjects.

2.2.2 Workstations

An ergonomic office chair and two single-leveled tables were used in this experiment (see Figure 1). Among the two tables, one is a non-adjustable table (Figure 1 (a)) and the other is an adjustable table (Figure 1 (c)). The work surface height of the non-adjustable table is 72 cm. An adjustment range of the work surface height of the adjustment table is 67-79 cm. The seat height of the adjustable office chair can be set as low as 40 cm and as high as 52 cm.

(a) Non-adjustable table (b) Adjustable chair (c) Adjustable table

Figure 1: Chair and tables used in the experiment

The chair and tables were grouped to form four types of workstations as follows:

- Type-1 workstation: fixed seat height and fixed work surface height
- Type-2 workstation: adjustable seat height and fixed work surface height
- Type-3 workstation: fixed seat height and adjustable work surface height

- Type-4 workstation: adjustable seat height and adjustable work surface height

For Type-1 and Type-3 workstations, the seat height is set at 45 cm.

2.2.3 Accessories

Four accessories are used to ergonomically adjust work postures of NBC users (see Figure 2). They are:

- *NBC base support*: an accessory placed on the work surface that helps to adjust the tilt angle of NBC and to raise its height to an appropriate level
- *Seat cushion*: an accessory placed on the chair seat that helps to raise the seat height so that the NBC user can be seated at the recommended level
- *Footrest*: an accessory placed on the floor that allows the NBC user to rest his/her feet comfortably; thus, preventing them from dangling
- *Document holder*: an accessory placed on the work surface at the side of the NBC that helps to hold a document at an appropriate angle for easy viewing

While a use of document holder is commonly recommended to prevent excessive neck flexion and twisting when viewing a document, *ErgoNBC* does not include this accessory in its computation.

(a) NBC Base Support (b) Document Holder (c) Footrest (d) Seat Cushion

Figure 2: NBC workstation accessories

2.3 *ErgoNBC*

ErgoNBC is a computer program which is intended to provide quantitative recommendations on the adjustment settings of NBC, workstation components (i.e., chair and table), and required accessories (e.g., NBC base support, seat cushion, and footrest).

2.3.1 Required Input Data

ErgoNBC requires three sets of input data for its computation algorithm to generate adjustment recommendations. They are:

1. *User's gender and body height*

The user's body height is used to estimate the following anthropometric data of an NBC user: eye height (sitting), shoulder height (sitting), upper arm length, lower arm length, hand length, popliteal height, and lower leg length. From the anthropometric data of Thai

population (TISI, 2001), a regression analysis is applied to determine the relations between body height and the anthropometric data listed above for each gender.

2. *Notebook computer size*

The size of NBC is usually indicated by the diagonal width (in inch) of its screen. *ErgoNBC* considers five common sizes of the NBCs used in Thailand: 11", 12", 13", 14", and 15". Three dimensions of NBC parts are required by the computation algorithm: distance from the front to rear edges of NBC base unit, distance from the front edge of NBC base to the keyboard's home row, and distance from the top to bottom edges of NBC screen unit.

3. *Workstation type and dimensions*

The workstation is categorized according to the adjustability of the seat and work surface heights. *ErgoNBC* considers four types of workstation: (1) fixed seat height – fixed work surface height, (2) adjustable seat height – fixed work surface height, (3) fixed seat height – adjustable work surface height, and (4) adjustable seat height – adjustable work surface height. The required dimensions are the chair seat height and work surface height. In a case of adjustable height, both the minimum and maximum levels are required.

2.3.2 Computation Algorithm and Adjustment Procedures

ErgoNBC utilizes the computation algorithm originally developed by Jalil and Nanthavanij (2007) and later improved by Nanthavanij et al. (2013a) to compute the recommended adjustment settings of NBC and workstation components by neglecting the workstation adjustability limits. That is, the algorithm places individual body parts to form a work posture according to the recommendations described earlier. Initially, the NBC user is assumed to be in a seated posture recommended by the ANSI/HFES 100-2007 Standard (2007). Next, relevant body joints and parts are sequentially adjusted so that the recommended posture during NBC work can be obtained (Nanthavanij et al., 2013a). Then, the NBC settings (i.e., tilt angle of NBC base, screen angle, and distance between the user's body and NBC) and workstation settings (i.e., seat height and work surface height) are determined from the co-ordinates and angles of corresponding body joints and parts, respectively.

The results obtained from the computation algorithm need to be evaluated by one of the four adjustment procedures according to the corresponding workstation type. They are:

1. Procedure for the workstation with fixed seat height and fixed work surface height
2. Procedure for the workstation with adjustable seat height and fixed work surface height
3. Procedure for the workstation with fixed seat height and adjustable work surface height
4. Procedure for the workstation with adjustable seat height and adjustable work surface height

More specifically, since the recommended seat and work surface heights are computed without considering the adjustment constraints of the workstation, they need to be compared to the fixed levels (in a case of fixed workstation components) or the minimum and maximum levels (in a case of adjustable workstation components). All four procedures consider the recommended seat height and work surface height as the starting workstation setting values.

2.3.3 Results

For practicality and convenience, *ErgoNBC* summarizes the recommended settings for the NBC, workstation components, and required accessories in separate sections. It also shows a graphic image of the suggested work posture. The recommendations are:

1. NBC settings (tilt angle of NBC base, screen angle, and distance between the body and NBC)
2. Workstation settings (seat height and work surface height)
3. Accessories (NBC base support, seat cushion, and footrest) and their settings

2.4 Experimental Procedure

Initially, the twelve NBC-workstation combinations (three NBC sizes and four workstation types) were randomly assigned to the twenty-four subjects. For each subject, the gender, body height, NBC size, and workstation data were entered into *ErgoNBC* to compute the recommended adjustment settings. Prior to the experiment, the subject was briefed about the purpose of the experiment and its procedure, and then signed the informed consent. He/she was explained about the workstation components and how to adjust their heights if applicable.

The experiment consisted of three trials. In the first trial, the subject was allowed to adjust the assigned NBC and workstation freely according to his/her preference. All four accessories were presented to the subject in case that they were needed. Once the subject finished adjusting the NBC and workstation, the experimenters measured all NBC and workstation settings and recorded on a data sheet. Then, the subject was instructed to perform a typing task by typing the text from the given document. The typing task lasted fifteen minutes, during which photos of work posture (front, side, and top views) were taken with a digital camera (at the 10^{th} minute of the task period). When the first trial was completed, the subject was allowed to sit at a resting area for ten minutes.

At the resting area, a poster of recommended body stretching and exercise techniques was installed and the subject was instructed to stretch fatigued body parts while resting. During the rest period, the experimenters re-set the NBC and workstation components according to the results generated by *ErgoNBC*. All required accessories were also set up at the workstation.

In the second trial, the subject was seated at the workstation and not allowed to adjust the

NBC and workstation components. The same typing task was performed for another fifteen minutes. The photos of work posture were taken at the 10th minute of the task period. When the second trial was over, the subject was allowed to rest and stretch fatigued body parts at the resting area for ten minutes. While resting, the subject was asked to fill out a questionnaire to compare the body comforts at selected body parts between the first and second trials.

The third trial is optional. If the subject wanted to re-adjust the NBC, workstation, and accessories, he/she had to complete the third trial. The same typing task was once again performed for fifteen minutes and another set of photos were taken at the 10th minute of the task period. At the end of the third trial, the subject was asked to compare the body comforts at the selected body parts between the third trial and any of the previous two trials that the subject felt producing more body comfort. However, if the subject was happy with the set-up of NBC and workstation in the second trial, he/she was exempted from the third trial.

3. RESULTS AND DISCUSSION

Figures 3 and 4 illustrate examples of work postures of two subjects when working with the NBC at their assigned workstations. The postures in trials T1, T2, and T3 are the preferred posture, recommended posture, and mixed posture, respectively. (Note that the mixed posture is the posture mixed between the preferred and recommended postures.) For the subject F3, she chose not to adjust the NBC and workstation any further and thus was exempted from the third trial.

T1 – Preferred Posture T2 – Recommended Posture T3 – Mixed Posture

Figure 3: Work postures of subject M9

T1 – Preferred Posture T2 – Recommended Posture

Figure 4: Work postures of subject F3

The Rapid Upper Limb Analysis (RULA) scores of the upper arm, lower arm, wrist, neck, trunk, and leg of all twenty-four subjects and three experimental trials were determined. Note that the lower the RULA score, the more appropriate the posture is. Table 1 summarizes the total numbers of subjects (both male and female) according to their RULA scores for the upper arm, lower arm, wrist, neck, trunk, and leg. In the first trial (T1), the subjects were likely to sit with awkward lower arm, wrist, and neck postures. Their upper arm, trunk, and leg were found to be quite acceptable. Nevertheless, some subjects adjusted the chair seat too low, causing the knee angle to be less than 90°. Several subjects also rested their feet on the prongs of chair base.

Table 1: Numbers of subjects per RULA score

RULA	Upper Arm			Lower Arm			Wrist			Neck			Trunk			Leg		
Score	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1	16	24	14	8	24	7	0	0	0	1	24	3	22	24	22	19	24	17
2	7	0	5	16	0	12	11	24	15	12	0	12	2	0	2	5	0	2
3	1	0	0	0	0	0	10	0	4	11	0	4	0	0	0	0	0	0
4	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0

It is obvious that *ErgoNBC* is able to improve the subjects' body postures (in the second trial, T2) by resulting in the lowest RULA scores of the upper arm, lower arm, neck, trunk, and leg. For the wrist, due to the small NBC keyboard size, it is almost inevitable that the subjects had to bend their wrists sideways (the ulnar deviation) when operating the keyboard. Thus, the RULA score of 2 is found to be the lowest score of the wrist.

In the third trial (T3), several subjects re-adjusted the NBC and workstation by lowering the chair seat, decreasing the NBC base tilt angle, leaning back too much on the backrest, and placing forearms on the work surface. It is believed that one of the reasons for re-adjusting the NBC and workstation was partly because they wanted to sit with the postures similar to their preferred postures. This is perhaps due to a short typing period which did not allow the effectiveness of the ergonomic work posture to be realized.

A paired *t*-test is employed to compare the RULA scores of individual body parts between two experimental trials. When comparing between the first trial (preferred posture) and the second trial (recommended posture), it is hypothesized that the RULA score of a given posture of the first trial is higher than that of the second trial since a higher score indicates a more awkward posture. Similarly, when comparing between the second trial (preferred posture) and the third trial (mixed posture), it is hypothesized that the RULA score of a given posture of the third trial is higher than that of the second trial.

3.1 Preferred Posture *vs*. Recommended Posture

For any body part, let d = RULA score of the preferred posture – RULA score of the recommended posture. Thus, the following hypotheses can be formulated:

H_0: $d \leq 0$ H_a: $d > 0$

Table 2 summarizes the statistical analysis results of the comparison between the RULA scores of the preferred posture and those of the recommended posture. The results show that the mean RULA scores of the recommended posture are significantly lower than those of the preferred posture of the upper arm, lower arm, wrist, neck, and leg. For the trunk, the difference is not significant. This finding leads to a conclusion that *ErgoNBC* is significantly effective in providing recommendations for adjusting the NBC and workstation.

Table 2: Results of paired *t*-tests (preferred posture *vs.* recommended posture)

Body Part	Mean RULA Score		df	*t*-Statistic	*P*-Value	Significant?
	Preferred Posture	Recommended Posture				
Upper arm	1.38	1.00	23	3.19	0.0020	Yes
Lower arm	1.63	1.00	23	6.19	< 0.0001	Yes
Wrist	2.67	2.00	23	4.65	< 0.0001	Yes
Neck	2.42	1.00	23	11.89	< 0.0001	Yes
Trunk	1.08	1.00	23	1.45	0.0808	No
Leg	1.21	1.00	23	2.46	0.0109	Yes

Note: df = degrees of freedom

3.2 Recommended Posture *vs*. Mixed Posture

For any body part, let d = RULA score of the mixed posture – RULA score of the preferred posture. Thus, the following hypotheses can be formulated:

H_0: $d \leq 0$ H_a: $d > 0$

Table 3 summarizes the statistical analysis results of the comparison between the RULA scores of the recommended posture and those of the mixed posture. In this comparison, five subjects (i.e., subjects M4, F3, F8, F10, and F11) who were exempted from the third trial were excluded. Thus, the number of subjects is 19 persons. The results show that the mean RULA scores of the recommended posture are significantly lower than those of the mixed posture of the upper arm, lower arm, wrist, and neck. For the trunk and leg, the differences are not significant. It can be concluded when the subjects were allowed to re-adjust the NBC and workstation, the postures of the upper arm, lower arm, wrist, and neck were worsened.

Table 3: Results of paired *t*-tests (recommended posture *vs.* mixed posture)

Body Part	Mean RULA Score		df	*t*-Statistic	P-Value	Significant?
	Recommended Posture	Mixed Posture				
Upper arm	1.00	1.21	18	2.19	0.0209	Yes
Lower arm	1.00	1.63	18	5.55	< 0.0001	Yes
Wrist	2.00	2.21	18	2.19	0.0209	Yes
Neck	1.00	2.05	18	7.39	< 0.0001	Yes
Trunk	1.00	1.11	18	1.46	0.0814	No
Leg	1.00	1.11	18	1.46	0.0814	No

Note: df = degrees of freedom

4. CONCLUSION

ErgoNBC is a spreadsheet-based computer program which is intended to provide adjustment recommendations for the NBC, workstation components, and some accessories. When the NBC and workstation are set according to the recommended adjustments, the NBC user is able to work with the computer with correct work posture. *ErgoNBC* is designed to be a user-friendly program. Its Input screen is designed for simplicity and convenience. The user needs to enter only the body height, gender, NBC size, and heights of workstation components. A built-in computation algorithm is employed to firstly compute the recommended settings of NBC and workstation components. Then, an appropriate adjustment procedure is used to recommend possible adjustments for chair seat and work surface heights. If necessary, some accessories and their settings are also recommended. The Results screen displays the input data and all recommendations in an easy-to-understand format. Additionally, the user can choose to print out the displayed information for his/her record.

The results of the validation experiment also confirm the effectiveness of *ErgoNBC*. Only the wrists still show the ulnar deviation as a result of typing on a small keyboard. Quantitatively, the RULA scores of selected body parts of the recommended posture are better (i.e., having a lower numerical value) than those of the preferred and mixed postures. The results of paired *t*-tests indicate that when comparing between the recommended and preferred postures and between the recommended and mixed postures, the differences in RULA scores are significant (at $\alpha = 0.05$) at the upper arm, lower arm, wrist, and neck.

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REFERENCES

Asundi, K., Odell, D., Luce, A., and Dennerlein, J.T. (2012) Changes in posture through the use of simple inclines with notebook computers placed on a standard desk, *Applied Ergonomics*, **43**, 400-407.

Culig, K.M., Dickinson, A.M., Lindstrom-Hazel, D., and Austin, J. (2008) Combining workstation design and performance management to increase ergonomically correct computer typing postures, *Journal of Organizational Behavior Management*, **28**, 146-175.

Hsiao, L.P. and Cho, C.Y. (2012) The effect of aging on muscle activation and postural control pattern for young and older computer users, *Applied Ergonomics*, **43**, 926-932.

Jalil, S. and Nanthavanij, S. (2007) Analytical algorithms for ergonomic seated posture when working with notebook computers, *Industrial Engineering and Management Systems*, **6**(2), 146-157.

Jalil, S., Nanthavanij, S., and Chalidabhongse, J. (2007) *PostureAdjuster*: decision support system for notebook computer operations. *Proceedings of the 8th Pan-Pacific Conference on Occupational Ergonomics, Bangkok, Thailand*, October, 2007.

Nanthavanij, S., Udomratana, C., Hansawad, S., Thepkanjana, J., and Tantasuwan, W. (2010) Practical worksheets for notebook computer and workstation adjustments. *Proceedings of the 10th Global Congress on Manufacturing and Management (GCMM2010)*, *Bangkok, Thailand*, 319-333.

Nanthavanij, S., Prae-arporn, K., Chanjirawittaya, S., Paripoonyo, S., and Rodloy, S. (2013a) Analytical determination of adjustment settings of notebook computer, workstation, and accessories for ergonomic work posture, *Working Paper Series, No. MT-1301*, Sirindhorn International Institute of Technology, Thammasat University, Thailand.

Nanthavanij, S., Prae-arporn, K., Chanjirawittaya, S., Paripoonyo, S., and Rodloy, S. (2013b) Spreadsheet-based program for ergonomic notebook computer and workstation adjustments, *Working Paper Series, No. MT-1302*, Sirindhorn International Institute of Technology, Thammasat University, Thailand.

Rempel, D.M., Krause, N., Goldberg, R., Benner, D., Hudes, M., and Goldner, G.U. (2006) A randomised controlled trial evaluating the effects of two workstation interventions on upper body pain and incident musculoskeletal disorders among computer operator, *Journal of Occupational and Environmental Medicine*, **63**, 300-306.

Shikdar, A.A. and Al-Kindi, M.A. (2007) Office ergonomics: deficiencies in computer workstation design, *International Journal of Occupational Safety and Ergonomics*, **13**, 215-223.

Thai Industrial Standards Institute (2001) *Report of the Survey and Research on the Anthropometric Data of Thai Population*, Ministry of Industry, Thailand.

The Human Factors and Ergonomics Society (2007) *Human Factors Engineering of*

Computer Workstations (ANSI/HFES 100-2007), The Human Factors and Ergonomics Society, Santa Monica, CA.

Wahlström, J. (2005) Ergonomics, musculoskeletal disorders and computer work, *Oxford Journals of Occupational Medicine*, **55**, 168-176.