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Analytical Design Methodology for Recommending VDT Workstation Settings and Computer Accessories Layout

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Abstract. Repetitive stress injury at the wrist has been reported as a common injury among visual display terminal (VDT) users (i.e., computer users). Adjusting a VDT workstation (computer table and chair) to maintain a correct seated posture while operating a keyboard is perhaps the most frequently recommended preventive solution. This paper proposes an analytical design methodology based on ergonomic design principles for recommending appropriate VDT workstation settings and layout of individual computer accessories on the computer table. The proposed design methodology consists of two interrelated phases: (1) determination of VDT workstation settings, and (2) design of computer accessories layout. Based on the information about the VDT user, dominant task to be performed, typing skill, and degrees of physical and visual interactions between the user and computer accessories, adjustment and layout solutions are recommended to allow having a correct seated posture while minimizing both physical and visual movements. The results from an experiment show that when adjusting the workstation and locating the computer accessories according to the recommendations given by the proposed design methodology, the user's hand movements can be significantly reduced.

Keywords: VDT workstation, adjustment settings, computer accessories layout, human-computer interaction

1. INTRODUCTION

Nowadays most office workers routinely use a computer to assist them in performing assigned tasks. Some workers use it on an intermittent basis while some do on a prolonged basis. It has been reported that long-term usage of computer (or visual display terminal – VDT) is a possible cause of carpal tunnel syndrome (CTS), neck tension syndrome (NTS), and low back pain. One of the risk factors that lead to developing these injuries is seating with improper posture while interacting with VDT. It is suspected that this improper seated posture is due to the following causes: (1) using a non-adjustable poorly design VDT workstation (i.e., computer table and chair), and (2) using an adjustable VDT workstation but failing to adjust its settings appropriately.

Generally, two ergonomic approaches for preventing and controlling CTS (the most common injury reported among VDT users) are eliminating occupational factors that contribute to the development of the syndrome and redesigning workstation and/or workplace (Babski and Crumpton, 1997). Workstation redesign is helpful to eliminate or minimize awkward postures of VDT users. The positioning of the keyboard relative to the user is a crucial factor affecting wrist posture and the risk of cumulative trauma injury (Hedge *et al*., 1996).

Ergonomic improvements in the design of VDT workstations and tasks have been widely embraced as a primary measure for preventing musculoskeletal disorders (MSD) problems in VDT work (Sauter and

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Schleifer, 1991). Key elements of an ergonomic VDT workstation include height-adjustable work surface, position-adjustable monitor, document holder, detachable keyboard, adjustable seating, wrist support, footrest (if necessary), and appropriate lighting and glare reduction (Gross and Hassel, 1991). Nanthavanij and Venezia (1999) suggested mathematical formulas that use body height to determine a set of workstation settings that are appropriate for an individual. The results (recommended workstation settings) were experimentally tested and found to be more effective in adjusting the VDT workstation than without it (Nanthavanij, 1996a; Nanthavanij, 1996b). Mekhora *et al*. (2000) also tested the effect of ergonomic intervention on discomfort in VDT users by adjusting their workstations according to the results from Nanthavanij and Venezia's formulas. Significant improvements were also found in that study. However, only the vertical heights (from the floor) and horizontal distances (from the VDT user) of the computer keyboard and monitor are the main emphases of those formulas.

A recent study by Cook *et al*. (2000) supported the importance of proper VDT workstation design in terms of positions and level heights of computer accessories. Both spatial factors were found to affect work posture. Most users are used to placing a mouse at the right side of a keyboard. This practice, as a result, causes increased activity in the deltoid and trapezius. Poor arrangement of computer accessories also forces the user to sit in constrained, unnatural, and stressful postures. There are other studies that also mentioned about the computer accessory arrangement but did not propose the solution (Hastings *et al*., 2000; Berns and Klusell, 2000). Berns and Klusell (2000) mentioned only placing an input device in front of the user as a recommended approach.

Another computer accessory that has been widely studied is a monitor. Ankrum and Nemeth (2000) reported that the monitor viewing angle in the range of 35°-38.5° below eye level is associated with head tilt and head/neck angles consistent with the "comfortable" postures. Straker and Mekhora (2000) categorized monitor positions into two groups: high monitor position (inclined backward 5° with the top of the monitor level with the subject's eyes), and low monitor position (inclined 25° backward and with the bottom of the monitor level with the desk). The study shows that subjects working with a high monitor position have less head, neck, and trunk flexion and less cervical and erector spinae muscle activity than when they work with a low monitor position.

Recently a field survey was conducted to investigate the effects of dominant input device and its location on the upper extremity discomforts of Thai VDT users (Rurkhamet and Nanthavanij, 2000). The results indicated that some computer accessories layout design strongly affects the physical discomforts at a wrist, lower arm, and upper arm, especially when a computer mouse is predominantly used. It was also recommended that the adjustment of VDT workstation settings and the layout of computer accessories be based on both user-related and task-related information.

2. PROPOSED DESIGN METHODOLOGY

2.1 Relevant Ergonomic Principles

The proposed design methodology utilizes several ergonomic principles that provide relevant guidelines/ recommendations for workstation design and arrangement of components. These principles, to some extent, can be adapted for the design of computer accessories layout. They are summarized in this section. For more details, readers are suggested to consult Sanders and McCormick (1993).

2.1.1 Anthropometric design principles

Anthropometric design principles give guidelines on how to utilize relevant anthropometric data in the design of products, equipment, and workstations. Specifically, it is necessary to know the body dimensions that are fundamentals for the design and define the population (of VDT users) that a VDT workstation is to be designed for. Since the VDT workstation is intended to be adjustable, the adjustment ranges (for individual features) must cover from the 5th percentile of the female population to the 95th percentile of the male population of each key body dimension.

2.1.2 Design of horizontal work surface

The horizontal work surface is usually used by "seated" or "sit-stand" workers to perform manual activities. It is essential to determine both the *work area* and the *work surface height*. Generally, all computer accessories should be located within the normal work area where they can be accessed conveniently. If the space is insufficient, those that are used more frequently or are more important should be located within the normal area while others will be located within the maximum area. For the height of the horizontal work surface for a seated worker, the following general guidelines may be followed.

1. Whenever possible, the work surface height (or at least the height of those portions where computer accessories are placed on) should be adjustable to fit individual physical dimensions and preferences.

2. The accessories to be operated by hand should be at the elbow height.

3. The work surface should provide adequate clearance for a person's thighs under the work surface.

2.1.3 Principles of arranging components

It is always recommended that each computer accessory be placed at its optimum location based on human capabilities and characteristics, sensory capabilities, and anthropometric and biomechanical characteristics. However, a conflict may occur when several accessories compete to occupy the same location. The following guidelines offer helpful solutions to the computer accessory arrangement problem. The approach involves two separate but interrelated phases: (1) the general location of computer accessories, and (2) the specific arrangement of computer accessories within a group of related accessories in that general location. Four arrangement principles are recommended for the above two phases.

1. Importance Principle: The "*importance*" principle recommends that important computer accessories be placed in convenient locations.

2. Frequency-of-Use Principle: The "*frequency-of-use*" principle recommends that frequently used computer accessories be placed in convenient locations.

3. Functional Principle: The "*functional*" principle recommends that computer accessories with functional similarity be grouped together.

4. Sequence-of-Use Principle: Should the sequences or patterns of relationship frequently occur in the operation of computer accessories, the accessories would then be so arranged as to take advantage of such patterns.

2.2 Design Assumptions

The proposed design methodology is based on the following assumptions.

1. The proper seated posture for prolonged VDT operations is as follows. *The VDT user should sit with the back at an upright position, the upper arm hanging naturally along the side, the elbow flexed 90°, the hand and the lower arm forming a straight line, the lower leg forming a right angle with the upper leg, and both feet resting comfortably on the floor* (ANSI/HFS 100-1988).

2. A VDT workstation consists of a fully adjustable computer table and a height-adjustable chair. The range of adjustment is sufficient to accommodate the 5^{th} percentile of female population to the 95^{th} percentile of male population.

3. Adjustable features of a VDT workstation include (1) keyboard tray, (2) mouse tray, (3) monitor platform, (4) document holder, (5) and chair seat.

4. Computer accessories include (1) computer keyboard, (2) mouse, (3) monitor, and (4) document holder.

2.3 Required Design Data

2.3.1 Data about VDT user, task, omputer accessories, and VDT workstation

Initially, it is necessary to gather data about a VDT user, task, computer accessories, and VDT workstation. The data can be grouped as "*quantitative*" and "*qualitative*" data as listed below.

Quantitative Data

- Age and body height of the VDT user.
- Adjustable ranges of seat, keyboard tray, mouse tray, and monitor platform.
- Dimensions of keyboard, mouse, monitor, and document.
- Percentage of time that each VDT task (*document preparation, numeric data entry, graphics design, and others*) is performed.
- Percentage of time that each input device (keyboard and mouse) is used.
- Percentage of time that each visual display device (monitor and document) is viewed.

Qualitative Data

- Gender (*male or female*) and typing skill level (*beginner, intermediate, or professional*) of the VDT user.
- Degrees of physical and visual interactions (*weak, moderate, or strong*) between the user and computer accessories based on the type of VDT task and typing skill level.
- Functional relationships (*weak, moderate, or strong*) among each pair of computer accessories in terms of physical and visual interactions.

2.3.2 Body reference points and anthropometric data

Based on the assumption of proper seated posture, the body reference points that are important for the proposed design methodology are ankle (A), knee (K), hip (H), shoulder (S), elbow (EL), fingertip (F), wrist (W), and eye (E). The anthropometric data of body segments that link adjacent reference points can be expressed as the proportion of body height. Table 1 shows the Thai anthropometric data as divided into four age groups for each gender (TISI, 1994).

2.3.3 Reference points of computer accessories

The reference point of a computer accessory is usually a point where the interaction (*either physical or visual*) between the user and the component takes place. If the dimensions of the component are known, it is then possible to determine the (x, y) coordinate of the reference point. Table 2 shows the dimensions of typical computer accessories (widely available in the market) and their reference points.

2.4 Determination of VDT Workstation Adjustment Settings

Based on the proper seated posture and the anthropometric data of the VDT user, it is possible to determine the (*x*, *y*) coordinate of each body reference point. Table 3 presents a list of formulas to determine these (*x*, *y*) coordinates (adapted with some modification from Nanthavanij and Venezia (1999)). After knowing these coordinates (of the body reference points), the coordinates of the reference points of computer accessories can be derived. For example, the coordinate of the fingertip is associated with that of the keyboard (or the mouse) reference point.

The VDT workstation settings that must be determined include seat level height, keyboard level height, mouse level height, monitor level height, and document level height. (All level heights are measured from the floor.) Furthermore, it is essential that the settings satisfy the VDT workstation constraints. That is, the level height of each workstation feature must be within its adjustable range. If not, certain adjustments must be performed. Note that the distances (from the user) are usually determined from the layout algorithm, not the adjustment algorithm.

Table 1. Anthropometric data (as proportions of body height) of body segments linking adjacent body reference points*

a) Female Population

Body Segment	Age Group			
	17-19 yr	20-29 yr	30-39 yr	40-49 yr
Lower Leg (LL)	0.2503	0.2490	0.2492	0.2495
Upper Leg (LL)	0.3524	0.3514	0.3551	0.3587
Trunk (T)	0.3402	0.3430	0.3467	0.3470
Upper Arm (UA)	0.1990	0.1982	0.2001	0.2008
Elbow-Fingertip (EF)	0.2163	0.2143	0.2163	0.2170
Shoulder-Eye (SE)	0.1110	0.1100	0.1091	0.1079
Thigh Thickness (TT)	0.0648	0.0644	0.0652	0.0656
Shoulder Height (SH)	0.5911	0.5933	0.5965	0.5965
Shoulder Width (SW)	0.2445	0.2477	0.2544	0.2593
Shoulder-Fingertip (SF)	0.3960	0.3964	0.3977	0.4003
Elbow-Eye (EE)	0.3100	0.3082	0.3092	0.3086
Lower Arm (LA)	0.1319	0.1313	0.1317	0.1326
Seated Height (SHE)	0.7760	0.7767	0.7773	0.7765

b) Male Population

Body Segment	Age Group			
	17-19 yr	20-29 yr	30-39 yr	40-49 yr
Lower Leg (LL)	0.2533	0.2521	0.2512	0.2515
Upper Leg (LL)	0.3491	0.3479	0.3488	0.3497
Trunk (T)	0.3437	0.3485	0.3536	0.3539
Upper Arm (UA)	0.2108	0.2102	0.2120	0.2139
Elbow-Fingertip (EF)	0.2743	0.2737	0.2729	0.2739
Shoulder-Eye (SE)	0.1138	0.1078	0.1084	0.1030
Thigh Thickness (TT)	0.0659	0.0653	0.0663	0.0667
Shoulder Height (SH)	0.5928	0.5964	0.6006	0.6012
Shoulder Width (SW)	0.2480	0.2545	0.2584	0.2600
Shoulder-Fingertip (SF)	0.4419	0.4521	0.4536	0.4558
Elbow-Eye (EE)	0.3192	0.3168	0.3163	0.3176
Lower Arm (LA)	0.1347	0.1332	0.1328	0.1330
Seated Height (SHE)	0.7731	0.7737	0.7747	0.7752

*Derived from the anthropometric data of Thai population (TISI, 1994)

Table 2. Dimensions and reference points of computer accessories

Computer Accessory[1]	Dimensions[2]	Reference Point
Keyboard (W x L x H)	16.0 x 45.5 x 3.0	
• *Alphabet Section*		*Between the "G" and "H" buttons*
• *Numeral Section*		*At the "5" button*
Mouse Pad (W x L)	17.0 x 21.0	At the top center of the pad
Monitor (W x L x H)	36.0 x 39.0 x 33.0	At the center of the screen
Document (W x L)	21.0 x 29.7	At the center of the page

[1]W = width, L = length, and H = height (or thickness) [2]All dimensions are in centimeters (cm).

2.5 Design of Computer Accessories Layout

The placement of components starts with the input devices. The percentages of keyboard and mouse usage are compared to determine the primary and secondary input devices. If the keyboard is the primary input device, it is necessary to know whether the alphabet section or the numeral section is predominantly used. The optimal locations of the primary and secondary input devices are where the device can be operated most conveniently within the normal area. If there is a location conflict between the two devices, an alternative location for the secondary device must be determined. Usually, it should be near the primary input device so that the hand movement between both devices is minimized.

For the visual displays, the percentages of monitor and document viewing (depending on the typing skill level of the user or task requirement) are initially compared to determine the primary and secondary visual displays. The location of the primary visual display is determined from the recommended viewing angle and distance. The secondary visual display is usually placed at its optimal location if it does not obstruct the viewing of the primary display. Otherwise, an alternative location that is near the primary display so that the head/neck movement is minimized must be determined.

For ease of understanding, the layout design process is summarized below. The design algorithm is also presented in the appendix.

Table 3. Formulas for calculating (*x*, *y*) coordinates of body reference points

Reference Point	Coordinate	Formula
Ankle (A)	*x*	$A_x = T\mathit{Sin}[BA] + UL\mathit{Cos}[SA]$
	y	$A_y = 0$
Knee (K)	*x*	$K_x = A_x$
	y	$K_y = A_y + LL + TT$
Hip (H)	*x*	$H_x = T\mathit{Sin}[BA]$
	y	$H_y = K_y - UL\mathit{Sin}[SA]$
Shoulder (S)	*x*	$S_x = 0$
	y	$S_y = H_y + T\mathit{Cos}[BA]$
Elbow (EL)	*x*	$EL_x = UA\mathit{Sin}[AA]$
	y	$EL_y = S_y - UA\mathit{Cos}[AA]$
Fingertip (F)	*x*	$F_x = EL_x + EF\mathit{Cos}[AA]$
	y	$F_y = EL_y + EF\mathit{Sin}[AA]$
Wrist (W)	*x*	$W_x = F_x - LA\mathit{Cos}[AA]$
	y	$W_y = F_y - LA\mathit{Sin}[AA]$
Eye (E)	*x*	$E_x = 12.70$ cm
	y	$E_y = S_y + SE$

I. <u>Locating Input Devices</u>

1. Determine the optimal locations of the primary and secondary input devices (based on their reference points, anthropometric data, dominant task, and task requirements). The following reference points are used.
   - Keyboard: Alphabet section – between the “G” and “H” buttons.
   - Numeral section – at the number “5” button.
   - Mouse: Its center (where the trackball is).
2. Place the primary input device at its optimal location and determine the occupied area from its dimensions (for the mouse, use the dimensions of the mouse pad).
3. Check if the optimal location of the secondary input device is outside the already occupied area and its dimensions do not overlap with the primary input device.
   - If yes, place the secondary input device at its optimal location. Go to *II: Locating Visual Displays*.
   - Otherwise, go to Step 4.
4. Determine the most preferable alternative location of the secondary input device (based on the functional relationships, reference points, anthropometric data, task requirement, and hand movement).
   - Keyboard: If the “*alphabet section*” is mostly used, place the keyboard at the left-hand side of the mouse pad where the reference point of that section is nearest to the mouse pad and is on the movement projectile of the right hand. If the “*numeral section*” is mostly used, place the keyboard such that its reference point is at the left-hand side of the mouse pad and is nearest to it.
   - Mouse: Place the mouse at the location that is nearest to the keyboard reference point (depending on the dominant VDT task) and on the movement projectile of the right hand.

II. <u>Locating Visual Displays</u>

1. Determine the optimal locations of the primary and secondary visual displays (based on their reference points, recommended viewing distance, dominant VDT task, typing skill level, and task requirement). The following reference points are used.
   - Monitor: Center of the screen
   - Document: Center of the page

   In case that the document is the primary visual display, go to Step 4. If both displays are equally important, go to Step 7. Otherwise, go to Step 2.
2. Place the monitor at the location right in front of the VDT user at the distance according to the ergonomic recommendation.
3. Place the document (and its holder) at either the right side or the left side of the monitor based on the user’s preference. The document should be closed to the monitor without obstructing its viewing. Keep the level height of the document close to that of the monitor to avoid excessive head movement. Go to Step 8.
4. Place the document at the location right in front of the VDT user at the distance according to the ergonomic recommendation.
5. If possible, place the monitor in front of the VDT user

(behind the document). These two conditions must be satisfied:
- The document must not obstruct the viewing of the monitor.
- The text shown on the screen must be satisfactorily visible, legible, and readable.

6. Otherwise, place the monitor at either the right side or the left side of the document based on the user's preference. The monitor should be close to the document without obstructing its viewing. Keep the level height of the monitor close to that of the document to avoid excessive head movement. Go to Step 8.
7. If both visual displays must be equally viewed by the VDT user, place them side by side right in front of the user. Which display should be on the left or on the right side depends on the user's preference. Place both displays adjacent to one another without overlapping to avoid excessive head movement.
8. End the layout design process.

3. EXAMPLE

Suppose that a VDT user is a 37-year old Thai male. Table 4 shows relevant physical and task data of this VDT user. The input data are entered into a computer program called EQ-DeX to determine the VDT workstation settings and layout of computer accessories that are appropriate for this person. EQ-Dex is written in Visual Basic according to the design methodology described earlier. The results (recommended settings and layout) generated by EQ-DeX are summarized in Table 5. Note that the horizontal location of a computer accessory is expressed as the location at the front of the user (with some distance to the left or to the right, or no deviation from the straight line projecting from the top of the user's head).

Table 4. Personal and task data of the VDT user in the given example

	Data
Nationality	Thai
Gender	Male
Age	37 years
Body Height	174 centimeters
Dominant VDT Task	Document preparation
Typing Skill Level	Beginner
Physical Interaction:	
- Keyboard	Strong
- Mouse	Weak
Visual Interaction:	
- Monitor	Strong
- Keyboard	Strong
-Document	Moderate
Keyboard Section Mostly Used	Alphabet

Table 5. Recommended workstations settings and locations of computer accessories

Workstation Feature/Computer Accessory[1]	Position/Location[2]
Computer Chair:	
-Seat Height Level	43 cm (from the floor)
-Foot Rest	Not required
Keyboard:	
-Height Level	68 cm (from the floor)
-Location (Alphabet Section)	41 cm (front of user) No deviation (to the left or to the right)
Mouse:	
-Height Level	68 cm (from the floor)
-Location	35 cm (front of user) 9 cm (to the left of user)
Monitor:	
-Height Level	91 cm (from the floor)
-Location	63 cm (front of user) No deviation (to the left or to the right)
Document:	
-Height Level	99 cm (from the floor)
-Location	76 cm (front of user) 14 cm (to the right of user)

Figure 1 shows the side-view picture of the subject at a fully adjustable VDT workstation in which its settings and the computer accessories are set according to the results presented in Table 5. The seat level height is set to allow the subject to sit comfortably with both feet resting firmly on the floor. With the knee angle of 90°, his thighs will not press against the edge of the chair; thus, preventing the occlusion of blood flow in both lower legs. The keyboard that is placed on the sliding tray is set at the same level as that of the

Figure 1. The subject's body posture when the workstation is adjusted according to the recommended settings

subject's fingertips. This level height also allows the subject to sit with a straight back posture, both upper arms hanging naturally along the body side, the elbow angle of 90°, and the hand forming a straight line with the lower arm. The horizontal position of the keyboard (the middle point between the "G" and "H" buttons) is set at the front of the subject since it is the primary input device (since the dominant task is document preparation). Specifically, it is at the intersection of the normal area boundaries (of both hands) so that he does not have to extend his arms while typing.

The mouse (the secondary input device) is recommended to be at the front of the subject, 9 cm to his left. While this position is rather unusual, it is based on the *sequence-of-use* principle and the functional relationship between the keyboard and the mouse. With the mouse at the recommended position, it is also on the movement projectile of the right hand and at the nearest position to the reference point of the alphabet section. Alternatively, the subject may choose to locate the mouse on the right side of the keyboard with its reference point also on the projectile of the right hand. This alternative location is particularly suitable if the sliding keyboard tray has limited width that makes it difficult to place the mouse between the user and the keyboard.

Both visual displays, monitor and document, are located at the level heights that require the subject to "*slightly look down*" when viewing. Since the monitor is the primary visual display, it is located right at the front of the subject. Thus, the document has to be placed at the right side of the monitor. To avoid excessive head/neck movement (from alternately viewing both displays), both displays are placed side by side.

It is seen that when adjusting the VDT workstation according to the recommended settings and computer accessories layout, the subject's seat posture is similar to the posture described in ANSI/HFS 100-1988.

4. EXPERIMENT AND RESULTS

4.1 Experimental Design

Twenty university students (15 males and 5 females) volunteered to participate without any compensation in an experiment to validate the proposed design methodology. Their age and body height ranges were 20-22 years and 155-180 cm, respectively. All subjects were given a typing test to classify their typing skill level into beginner, intermediate, or professional. Four professional-level typists, four intermediate-level typists, and four beginner-level typists were randomly chosen to perform the document preparation task. Among the remaining eight subjects, four were assigned the graphics design task while the other four the numeric data entry task. Each VDT task lasted 30 minutes.

4.2 Data Collection and Analysis

Each subject had to perform the assigned task two times, with at least three days apart between the tasks. In the first test, the subject was asked to adjust the VDT workstation settings and place the computer accessories as one preferred. All the settings and accessory locations were recorded and reference point coordinates measured. All paired distances between computer accessories (input devices and visual displays) were measured and recorded prior to the test. During the test, the subject's hand movements were recorded on the videotape for future analysis. Only one video camera is used in the experiment. Its location was carefully chosen so that the subject's hand movements could be clearly recorded.

In the second test, the workstation settings and accessory locations were set according to the recommendations given by the proposed design methodology (for each individual). However, the subject was allowed to readjust the VDT workstation if desired. Once again, all paired distances between computer accessories (input devices and visual displays) were measured and recorded. The test materials and test conditions were the same as those used in the first test. Hand movements were also recorded on the videotape.

At the end of each test, the videotape was played back and the number of hand (left and right) movements was counted. The total movement distance (in cm) is the product of the distance between the input devices and the number of hand movements. Then, the difference in movement distances was determined by subtracting the total movement distance from the second test by that from the first test. It was hypothesized that the workstation adjustment based on the recommendations would result in a smaller total movement distance since the workstation components and computer accessories were placed at their appropriate levels and/or locations.

The order of the test was the same for every subject. This is to prevent any influence that the recommendations derived from the design methodology might have on the subject's preference on the VDT workstation settings.

4.3 Results

Table 6 shows how much the proposed design methodology can help to reduce the subject's hand movements while performing the assigned task. The numbers shown are the average values from all subjects who performed that task. Note that in the first test, the workstation settings and layout of computer accessories were decided by the subject, while in the second test, they were recommended by the proposed design methodology. The differences are presented as negative values to indicate the decrease in hand movements.

For the document preparation task, irrespective of the typing skill level, the average hand movement distances were decreased by more than 75%. When comparing the differences in each VDT task using the

Table 6. Comparisons between the hand movements from both tests of each VDT task

VDT Task*	Average Hand Movement (cm)		Average Difference (cm)	% Difference
	First Test	Second Test	(Second Test – First Test)	
Document Preparation – P	1914.8	409.4	-1505.4	-78.62 %
Document Preparation – I	1366.6	295.3	-1071.3	-78.39 %
Document Preparation – B	927.3	212.3	-715.0	-77.11 %
Graphics Design	6612.6	1873.4	-4739.2	-71.67 %
Data Entry	4561.1	3426.6	-1134.5	-24.87 %

*P = Professional, I = Intermediate, B = Beginner

paired *t*-test, the differences were found to be significant (α = 0.05) for all VDT tasks. Therefore, it could be concluded that the recommendations given by the proposed design methodology significantly decreased hand movements of subjects while performing VDT tasks. Consequently, it is believed that by adjusting the VDT workstation and arranging the layout of computer accessories according to the results from the proposed design methodology, the physical discomforts that VDT users usually experience as a result of prolonged VDT operation can be reduced.

5. CONCLUSION

The proposed design methodology provides "practical" recommendations on *how* a VDT workstation should be adjusted and *where* computer accessories should be placed on the computer table, so that the VDT user can sit with a proper seated posture. Such recommendations are based on specific information about the user, task, VDT workstation, and computer accessories. Although the methodology is based on certain assumptions and does not use individual anthropometric data, it is believed that the recommendations can be effectively used as an initial solution that is very close to the best solution. The VDT user might need to do "*minor fine tuning*" on such recommendations to obtain the "*perfect*" fit.

Although the VDT workstation adjustment topic has already been widely studied, most published recommendations are found to be descriptive (and somewhat vague) which require VDT users to decide by themselves about specific settings. The input device mentioned in nearly all recommendations is only the computer keyboard. Very few studies, if any, have paid attention to the computer mouse. Moreover, existing recommendations seem to emphasize only on the level heights and distances. The layout of computer accessories has not been seriously considered. This design methodology integrates both the determination of workstation settings and the design of optimal layout to generate its recommendations based on relevant ergonomics principles. Since the results are quantitative, VDT users should find the recommendations practical and the adjustment process easy to perform. It is noted that in order for the proposed design methodology to be effectively applied, the VDT workstation (both the computer table and chair) must be fully adjustable. This should not be a major obstacle nowadays since there are a wide range of adjustable computer tables and chairs presently available in the market.

For other types of input devices such as a touch screen, it is possible to modify the design algorithm (both the adjustment settings and computer accessories layout) to account for its presence and functions. Since the touch screen will be both the input device and visual display device, it is necessary to firstly determine its dominant role. If it is used mostly as an input device, then its location will be based on the physical interaction between the VDT user and the touch screen. If its dominant role is to display information, then its location will be based on the visual interaction instead.

This methodology helps to make VDT workstation adjustment and computer accessories layout design easy and practical. The results from the experiment also show that the given recommendations help to significantly reduce the subject's hand movements while working with the VDT, irrespective of the VDT task. Thus, when the VDT user can sit with the proper seated posture, it is expected that the postural stresses especially at the upper extremities will be reduced.

The major contribution of the proposed design methodology is to allow VDT users to sit more appropriately (with a correct seated posture) when performing a VDT task so as to reduce the body part discomfort (especially in the upper extremities). In the long term, it is anticipated that the occurrence of musculoskeletal disorders (MSD) would be reduced since one risk factor (i.e., awkward posture) is eliminated.

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APPENDIX : Design Algorithm

The variables used in this section are abbreviated as follows: viewing angle (VA), viewing distance (VD), arm angle (AA), back angle (BA), seat angle (SA), monitor (M), document (D), and body center (Cbody). The subscripts show the coordinate axis and position of the point (on the component). For example, M_{YLR} represents the *y*-coordinate of the lower right corner of the monitor.

1. Initialization
   1.1 Define VA = 36.75°, VD = 63.5 cm, Foot rest = 0 cm, Raise hand = 0 cm, AA = 0°, BA = 0°, and SA = 0°.
   1.2 Calculate (*x*, *y*) coordinates of body reference points using the formulas given in Table 3.
2. Determine (x, y) coordinates of the workstation's reference points
   Assign $Keyboard_x$ = $Fingertip_x$ and $Keyboard_y$ = $Fingertip_y$ + Foot rest
3. Check the seat level height
   3.1 Check the lower limit of the seat level height.
   If $Knee_y \geq SeatHeight_{LowerLimit}$, go to Step 3.2.
   Otherwise, Foot rest = $Knee_y - SeatHeight_{LowerLimit}$ and go to Step 2.
   3.2 Check the upper limit of the seat level height.
   If $Hip_y \leq SeatHeight_{UpperLimit}$, go to Step 4.
   Otherwise, lower Hip_y, $Shoulder_y$, $Elbow_y$, $Fingertip_y$, $Wrist_y$, and Eye_y with $Hip_y - SeatHeight_{UpperLimit}$, go to Step 2.
4. Check the keyboard level height
   4.1 If $KeyboardHeight_{LowerLimit} \leq Fingertip_y \leq KeyboardHeight_{UpperLimit}$, go to Step 7. Otherwise, go to Step 4.2.
   4.2 If $Fingertip_y \geq KeyboardHeight_{UpperLimit}$, go to Step 6.3. Otherwise, go to Step 4.3.
   4.3 If Problem1* does not exist, go to Step 6.3. Otherwise, go to Step 4.4.
   4.4 Set AA = 0°.
5. Check the fingertip level height with the lower limit of the keyboard height
   5.1 Check the fingertip level height (within limit).
   If $Fingertip_y \geq KeyboardHeight_{LowerLimit}$, go to Step 2. Otherwise, go to Step 5.2.
   5.2 Raise hand
   If Raise hand > 0, go to Step 6.1; otherwise, go to the next step.
   Raise hand = $KeyboardHeight_{LowerLimit} - Fingertip_y$.
   If $Knee_y$ + Raise hand < $SeatHeight_{UpperLimit}$, go to Step 1.2; otherwise, go to the next step.
   Raise hand = $SeatHeight_{UpperLimit} - Knee_y$.
   If Raise hand = 0, go to Step 6.1; otherwise, go to Step 1.2.
6. Check the arm angle, increase if necessary and limit at 14 degrees
   6.1 Raise fingertip I
   AA = AA + 1°.
   Recalculate $Elbow_{x,y}$, $Fingertip_{x,y}$, and $Wrist_{x,y}$ with new arm angle.
   If AA < 15°, go to Step 5.1; otherwise, reset AA to 0°and go to Step 6.2.
   6.2 Raise fingertip II
   While, AA < 15°, then AA = AA + 1°, recalculate $Elbow_{x,y}$, $Fingertip_{x,y}$, and $Wrist_{x,y}$ with new arm angle until $Fingertip_y \geq KeyboardHeight_{LowerLimit}$ and go to Step 2.
   If $Fingertip_y < KeyboardHeight_{LowerLimit}$, Problem1* exists. Go to Step 2.
   6.3 Check the fingertip level height (if out of limit)
   If $Fingertip_y < KeyboardHeight_{LowerLimit}$, go to Step 6.1; otherwise, go to Step 6.4.
   6.4 Lower the fingertip level height
   If Problem2* exists, go to Step 7; otherwise, go to the next step.
   If AA < -15°, Problem2* exists and go to Step 2; otherwise, go to the next step.
   AA = AA – 0.1°. Go to the next step.
   Recalculate $Fingertip_{x,y}$ and $Wrist_{x,y}$. Go to the next step.
   If $Fingertip_y \leq KeyboardHeight_{UpperLimit}$, go to Step 2; otherwise, go to Step 6.4.
7. Locate the input devices
   If percent of keyboard usage ≥ percent of mouse usage, then keyboard is the primary input device and mouse is the secondary one; otherwise, mouse is the primary input device, and keyboard is the secondary one.
   If percent of alphabet section usage > percent of numeral section usage, then the reference point of the alphabet section is considered. Otherwise, the reference point of the numeral section is.
   Calculate the optimal locations of the primary and secondary input devices.
   Place the primary input device at its optimal location.
   Check the overlapping condition between the locations of the primary and secondary input devices.
   If no overlapping occurs, place the secondary input device. Otherwise, an alternative location is calculated and the secondary input device can be located without overlapping with the primary input device.
8. Locate the visual displays
   8.1 If the visual interaction with the monitor > the visual interaction level with the document, place the monitor at the front (Step 8.1.1) and document at left side (Step 8.1.2).
   8.1.1 Place the monitor at the front.
   Calculate M_{XLR}, M_{MLR}, and M_{ZLR}.
   Use M_{YLR} for checking overlapping condition with input devices. If there is, M_{YLR} will be increased until the overlapping condition disappears.
   Calculate M_{XLL}, M_{YLL}, and M_{ZLL} based on

LR.

Calculate M_{CX}, M_{CY}, M_{CZ}, M_{XUL}, M_{YUL}, M_{ZUL}, M_{XUR}, M_{YUR}, and M_{ZUR}.

8.1.2 Place the document at the left side.

If Document Usage = 0, the algorithm is completed. Otherwise, go to the next step.

Set $D_{XLR} = M_{XLL} – 1$.

Calculate the distance between the body center and D_{XLR} based on the recommended viewing distance and viewing angle.

Calculate D_{XLR}, $D_{YLR,}$ and D_{ZLR}.

Calculate the angle (alpha) that the document forms with the *x*-axis.

Recalculate D_{YLR} in order to avoid overlapping condition with keyboard.

Calculate D_{CX}, $D_{CY,}$ and D_{CZ}.

If D_{ZLR}>$Monitor_{UpperLimit}$, set D_{ZLR} = $Monitor_{UpperLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If D_{ZLR}<$Monitor_{UpperLimit}$, set D_{ZLR} = $Monitor_{LowerLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If the recommended viewing angle > 60°, set the recommended viewing angle to 60°. Otherwise, go to the next step.

If the recommended viewing angle < 0°, set the recommended viewing angle to 0°. Otherwise, go to the next step.

Calculate D_{XLL}, $D_{YLL,}$ D_{ZLL}, D_{XUR}, $D_{YUR,}$ D_{ZUR}, D_{XLR}, $D_{YLR,}$ D_{ZLR}, D_{CX}, $D_{CY,}$ and D_{CZ}. The algorithm is completed.

8.2 If the visual interaction with the monitor < the visual interaction with the document, then place the document at the front (Step 8.2.1) and monitor at the left side (Step 8.2.2).

8.2.1 Place the document at the front.

Calculate D_{XLR}, D_{YLR}, and D_{ZLR}.

Use D_{YLR} for checking the overlapping condition with input devices. If there is, D_{YLR} will be increased until the overlapping condition disappears.

Calculate D_{XLL}, D_{YLL}, and D_{ZLL} based on D_{LR}.

Calculate D_{CX}, C_{CY}, D_{CZ}, D_{XUL}, D_{YUL}, D_{ZUL}, D_{XUR}, D_{YUR}, and D_{ZUR}.

8.2.2 Place the monitor at the left side.

Set $M_{XLR} = D_{XLL} – 1$.

Calculate the distance between the body center and M_{XLR} based on the recommended viewing distance and viewing angle.

Calculate M_{XLR}, $M_{YLR,}$ and M_{ZLR}.

Calculate the angle (alpha) that the monitor forms with the *x*-axis.

Recalculate D_{YLR} in order to avoid the overlapping condition with keyboard.

Calculate M_{CX}, $M_{CY,}$ and M_{CZ}.

If M_{ZLR} > $Monitor_{UpperLimit}$, set M_{ZLR} = $Monitor_{UpperLimit}$ and recalculate the recommended the viewing angle and alpha. Otherwise, go to the next step.

If M_{ZLR} < $Monitor_{UpperLimit}$, set M_{ZLR} = $Monitor_{LowerLimit}$ and recalculate the recommended the viewing angle and alpha. Otherwise, go to the next step.

If the recommended viewing angle > 60°, set the recommended viewing angle = 60°. Otherwise, go to the next step.

If the recommended viewing angle < 0°, set the recommended viewing angle to 0°. Otherwise, go to the next step.

Calculate M_{XLL}, $M_{YLL,}$ M_{ZLL}, M_{XUR}, $M_{YUR,}$ M_{ZUR}, M_{XLR}, $M_{YLR,}$ M_{ZLR}, M_{CX}, $M_{CY,}$ and M_{CZ}. The algorithm is completed.

8.3 If the visual interaction with the monitor = the visual interaction with the document, then place the document at the left side (Step 8.3.1) and place the monitor at the right side (Step 8.3.2).

8.3.1 Place the document at left side.

Set $D_{XLR} = Cbody_X$.

Calculate the distance between the body center and D_{XLR} based on the recommended viewing distance and viewing angle.

Calculate $D_{YLR,}$ and D_{ZLR}.

Find the angle (alpha) that the document forms with the *x*-axis.

Calculate D_{XLL}, $D_{YLL,}$ D_{ZLL}.

Recalculate D_{YLR} in order to avoid the overlapping condition with keyboard.

Calculate D_{CX}, $D_{CY,}$ and D_{CZ}.

If D_{ZLR} > $Monitor_{UpperLimit}$, set D_{ZLR} = $Monitor_{UpperLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If D_{ZLR} < $Monitor_{UpperLimit}$, set D_{ZLR} = $Monitor_{LowerLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If the recommended viewing angle > 60°, set the recommended viewing angle to 60°. Otherwise, go to the next step.

If the recommended viewing angle < 0°, set the recommended viewing angle to 0°. Otherwise, go to the next step.

Recalculate D_{CX}, D_{CY}, D_{XLL}, $D_{YLL,}$ D_{ZLL}, D_{XUR}, $D_{YUR,}$ D_{ZUR}, $D_{YLR,}$ and D_{ZLR} with new viewing distance, viewing angle, and alpha. Go to Step 8.3.2.

8.3.2 Place the monitor at the right side.

Set M_{XLL} = $Cbody_X$

Calculate the distance between the body center and M_{XLL} based on the recommended viewing distance and viewing angle.

Calculate M_{XLL}, $M_{YLL,}$ and M_{ZLL}.

Find the angle (alpha) that the monitor forms with the *x*-axis.

Calculate M_{XLR}, $M_{YLR,}$ M_{ZLR}

Recalculate D_{YLR} in order to avoid the overlapping condition with keyboard.

Calculate M_{CX}, $M_{CY,}$ and M_{CZ}.

If M_{ZLR}>$Monitor_{UpperLimit}$, set M_{ZLR} = $Monitor_{UpperLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If M_{ZLR}<$Monitor_{UpperLimit}$, set M_{ZLR} = $Monitor_{LowerLimit}$ and recalculate the recommended viewing angle and alpha. Otherwise, go to the next step.

If the recommended viewing angle > 60°, set the recommended viewing angle = 60°. Otherwise, go to the next step.

If the recommended viewing angle < 0°, set the recommended viewing angle to 0°. Otherwise, go to the next step.

Recalculate M_{CX}, M_{CY}, M_{XLL}, $M_{YLL,}$ M_{ZLL}, M_{XUR}, $M_{YUR,}$ M_{ZUR}, $M_{YLR,}$ and M_{ZLR} with new viewing distance, viewing angle, and alpha. The algorithm is completed.

End.

**Note : Problem1 is "the optimal keyboard level height is lower than the lower limit."*

Problem2 is "the optimal keyboard height level is higher than the upper limit."

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