The Ergonomics Virtual Reality Station Design (ErgoVR)

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Abstract. *Virtual reality (VR) is a promising technology which has the ability to immerse a user in a virtual world through the use of 3D real time computer graphics. The user works "together" with the virtual objects to complete the desired task. Therefore, a physical environment is needed to make the users feel, see and interact with virtual objects in the most natural and ergonomic position so that the unnecessary awkward posture and others physical discomfort that could be detrimental to the users of the virtual system can be avoided. The objective of this research is to design an Ergonomic virtual reality station that will reduce the unnecessary awkward posture and others physical discomfort when using VR system. Anthropometrics data was collected from Malaysian population. Statistical analysis was conducted to analyze the uniformity of anthropometrics data and required number of sample. Result of the research shows that the appropriate design to the anthropometrics data of users will be able to reduce the awkward posture and others physical discomfort.*

Key word: *Virtual reality, ergonomics workstation design, awkward posture, physical discomfort*

1. INTRODUCTION

In a virtual reality system, the user works "together" with the virtual objects to complete the desired task. The workstation co-locates the 3-D view, virtual objects and user's hand which the user can see and interact with the virtual objects in the same place, as shown in Figure 1.

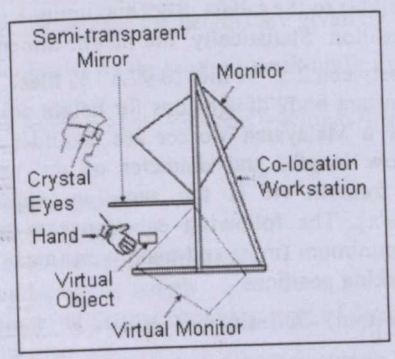

Figure 1: Concept of Co-location workstation

Therefore, a physical environment is needed to make the users feel, see and interact with virtual objects in the most natural and ergonomic position so that the unnecessary awkward posture and others physical discomfort that could be detrimental to the users of the virtual system can be avoided.

In this system, users complete the task within the virtual environment. The use of adjustable design principle for the workstation is to optimize for the variability person's size and shape. The workstations also allow users to feel more comfortable and afford full concentration.

Some researchers have taken great interest on human computer interaction partially focusing on office computer workstation. Unfortunately there is still little research related to virtual reality system.

The objective of this study is to design an Ergonomics virtual reality (ErgoVR) station based on Malaysian users.

2. MATERIAL AND METHOD

2.1 Subject

A direct measurement of body dimension was conducted on Malaysian university students (241 Males, 98 Females). This mean age was 25.7 years old (aged 17-35 years). The anthropometrics data comprises of several

body dimensions including shoulder height, shoulder elbow length, the proximal segment circumference of forearm, popliteal height, shoulder height from seat, arm reach forward length, forearm-hand length, shoulder breadth, hip breadth, and buttock to popliteal length. The direct measurement was conducted using an anthropometer.

Prior to the measurement, informed consent was obtained about the objectives of the measurement as well as participant rights were fully explained.

2.2 Statistical analysis

Statistical analysis was conducted to analyze the uniformity of the anthropometrics data and the required number of sample. A Control chart was used to identify the data that is out of control at 99% confidence level. Data that is out of the upper control limit (UCL) or lower control limits (LCL) are considered as non uniform data and discarded. An acceptance or adequacy test was used to determine the required sample size (N') based on the normal distribution. The level of significance of this test was set at 5%. The criterion of acceptance is $N' \leq n$, in which the required sample size is less than the collected real sample (n).

2.3 Procedure of Design

Tayyari and Smith (1997) explained the following procedure for the use of anthropometric data in workstation design:

1. Define the potential user population
2. Choose the proportion of the population to be accommodated by the design
3. Determine the body dimensions important in the design
4. Determine the type of accommodation (reach or clearance situation)
5. Determine the percentile values of the dimensions for the chosen proportion of the population
6. Determine the relevant personal equipment allowance.

The proportion of the population to be accommodated is set at 95% for the entire body dimension. It means 95% of potential user will be able to use the design without adjustment while the remaining population should be able to adjust it.

3. RESULTS

3.1 The Uniformity and Acceptance Test of the Anthropometric Data

Table 1 describes the result of the uniformity and acceptance test for the entire anthropometric data shown in uniformly data.

Table 1. Result of the uniform test and adequate test of Anthropometric data (Male = 241, Female = 98)

Body dimension		Mean	UCL	LCL	N'	Decision	
sh	*M*	1343	1485	1201	225	uniform	accepted
	F	1257	1376	1138	81	uniform	accepted
sel	*M*	351	414	288	199	uniform	accepted
	F	313	369	257	77	uniform	accepted
d	*M*	81.85	103	60	235	uniform	accepted
	F	81.85	109	54	87	uniform	accepted
ph	*M*	391	447	335	221	uniform	accepted
	F	370	428	312	85	uniform	accepted
sh_seat	*M*	566	645	487	232	uniform	accepted
	F	538	603	473	88	uniform	accepted
arm_rfL	*M*	822	938	706	222	uniform	accepted
	F	767	858	676	79	uniform	accepted
arm_fhL	*M*	455	527	383	210	uniform	accepted
	F	427	499	355	83	uniform	accepted
sb	*M*	425	490	360	215	uniform	accepted
	F	403	494	312	75	uniform	accepted
hb	*M*	322	394	250	240	uniform	accepted
	F	353	444	262	89	uniform	accepted
bpl	*M*	435	547	323	225	uniform	accepted
	F	437	544	330	86	uniform	accepted

Where,

sh : Shoulder height
sel : Shoulder elbow length
d : diameter of the proximal segment of forearm
ph : Popliteal height
sh_seat : Shoulder height from seat
arm_rfL: Arm reaches forward length
arm_fhL: Forearm-hand length
sb : Shoulder breadth
hb : Hip breadth
bpl : Buttock to popliteal length

3.2 Worktable Height Dimension for the Standing Position

The worktable height is adjustable. It can accommodate 95% of the population from a shortest user (minimum height) to the tallest user (maximum height) in a standing position. Statistically, the height dimension is in the range between 2.5^{th} % tiles to 97.5^{th} % tiles.

The important body dimensions for height adjustable worktable for a Malaysian worker are shoulder height, shoulder elbow length, and diameter of the proximal segment of forearm (it is the same as upper arm circumference/π). The following equations are used to obtained the minimum (min) and maximum (max) height in various working positions

$$wh(\min) = sh(\min) - sel(\min) + d(\min) + e \quad \ldots\ldots (1)$$

$$wh(\max) = sh(\max) - sel(\max) + d(\max) + e \quad \ldots\ldots (2)$$

where,

wh : worktable height
sh : shoulder height
sel : shoulder elbow length

d : diameter of the proximal segment of forearm
e : allowance

The allowance provided for motion in standing position is 50 mm. By using the dimensions in Appendix and equations 1 and 2, the minimum and maximum worktable heights were found to be 999.79 mm and 1,213.58 mm, respectively. Figure 2 shows the design of the workstation for a standing position.

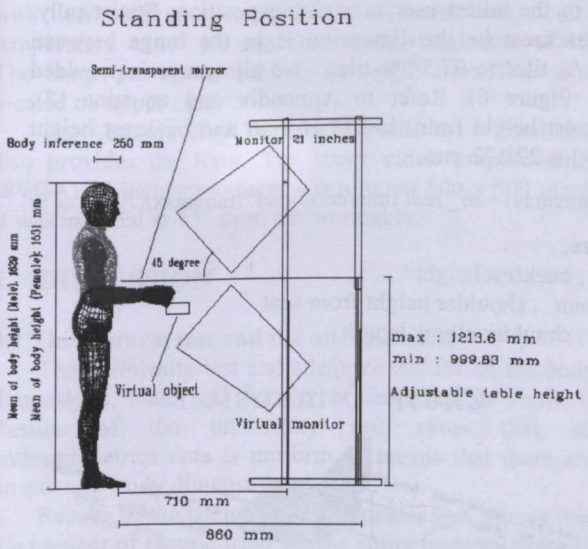

Figure 2: Ergonomic workstation design for standing position

3.3 Worktable Height Dimension for the Sitting Position

The important body dimensions for a sitting position user are popliteal height, shoulder height from seat (sitting), shoulder elbow length, and diameter of the proximal segment of forearm (it is the same as upper arm circumference/π). Allowance provided for motion is 50 mm. The equations for the heights are given by

$$wh(\min) = ph(\min) + [sh\_seat(\min) - sel(\min)] + d(\min) + e \quad (3)$$

$$wh(\max) = ph(\max) + [sh\_seat(\max) - sel(\max)] + d(\max) + e. \quad (4)$$

where,
wh : worktable height
ph : popliteal height
sh_seat : shoulder height from seat
sel : shoulder elbow length
d : diameter of the proximal segment of forearm
e : allowance

The minimum and maximum worktable height in a sitting position is found to be 646.91 mm and 821.70 mm respectively. Figure 3 shows the design of the workstation for a sitting position.

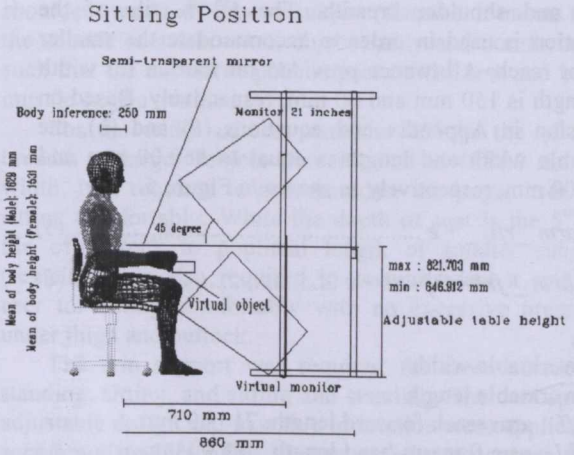

Figure 3: Ergonomic workstation design for sitting position

3.4 Worktable Height Dimension for the Sitting and Standing Position

The minimum worktable height in the sitting and standing position is the maximum worktable height in the sitting position (821.70 mm). While the dimension for the maximum worktable height in sitting and standing position refers to the minimum worktable height in the standing position (999.79 mm). The design is shown in Figure 4.

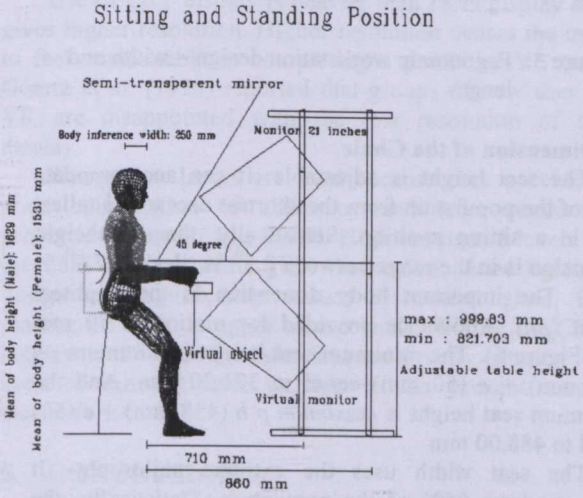

Figure 4: Ergonomic workstation design for sitting & standing position

3.5 Worktable Width and Length

The worktable width and length also uses the extreme philosophy. It accommodates 95% of the population. Statistically, these dimensions are the 5th % tiles or 95th % tiles. The important body dimensions in worktable width and length are arm reaches forward length, forearm-hand

length and shoulder breadth. The 5th % tile of the population is used in order to accommodate the smaller user for reach. Allowance provided for motion for width and length is 150 mm and 50 mm, respectively. Based on dimension in Appendix and equations (5) and (6), the worktable width and length is equal to 860.00 mm and 1,202.00 mm, respectively as shown in Figure 5.

$$ww = arm\_rfL\_ + e \quad \text{.....(5)}$$

$$wl = (arm\_fhL \times 2) + sb + e \quad \text{..... (6)}$$

where,
ww : worktable width
wl : worktable length
arm_rfL : arm reach forward length, 710.00 mm
arm_fhL : arm forearm-hand length, 398.00 mm
sb : shoulder breadth, 356.00mm
e : allowance

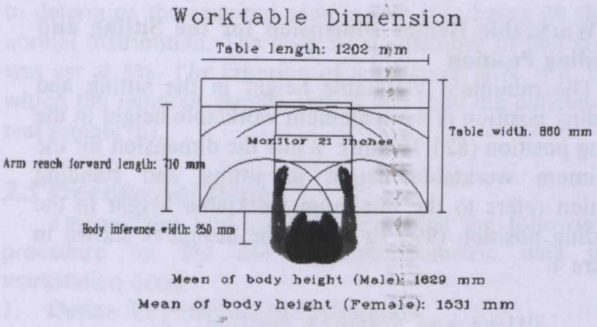

Figure 5: Ergonomic workstation design – width and length

3.6 Dimension of the Chair

The seat height is adjustable. It can accommodate 95% of the population from the shortest user to the tallest user in a sitting position. Statistically, the seat height dimension is in the range between 2.5th % tiles to 97.5th % tiles. The important body dimension is the popliteal height (*ph*). Allowance provided for motion is 50 mm (See Figure 6). The minimum seat height is minimum *ph* (321 mm) + *e* (50 mm) equal to 371.00 mm. And the maximum seat height is *maximum p h* (438 mm) + *e* (50) equal to 488.00 mm

The seat width uses the extreme philosophy. It accommodates 95% of the population. Statistically, the seat width dimension is on the 5th % tiles or 95th % tiles. The important bodies dimension for seat width design is the hip breadth (*hb*). The 95th % tile of the population is used in order to accommodate the larger user when sitting. Allowance provided for clothes is 10 mm (See Figure 6). Seat width is *hb* (415 mm) + *e* (10 mm) equal to 425.00 mm.

The seat depth uses the extreme philosophy. It accommodates 95% of the population. Statistically, the seat depth dimension is on the 5th % tiles or 95th % tiles. The important bodies dimension for seat depth design is the buttock to popliteal length (*bpl*). The 5th % tiles of the population is used in order to accommodate the smaller user when sitting. Allowance provided for clothes is 10 mm (See Figure 6). Seat depth is *lbpl* (380 mm) + e (10 mm) equal to 390.00 mm

The height of the backrest is adjustable. It can accommodate 95% of the population from the shortest user to the tallest user in a sitting position. Statistically, the backrest height dimension is in the range between 2.5th % tiles to 97.5th % tiles. No allowance is provided (See Figure 6). Refer to Appendix and equation (7), backrest height (min) is 217.16 mm and backrest height (max) is 228.72 mm.

$$bh\ (\text{min/max}) = sh\_seat\ (\text{min/max}) - sel\ (\text{min/max}) \quad \text{.....(7)}$$

where,
bh : backrest height
sh_seat : shoulder height from seat
sel : shoulder elbow length

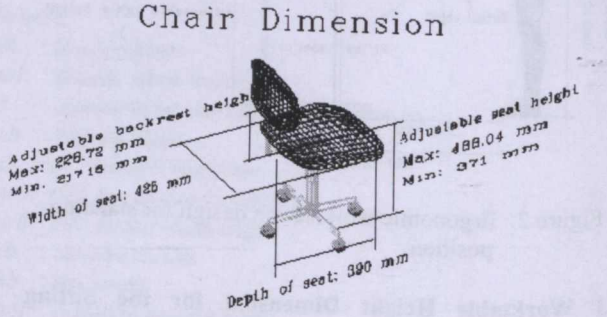

Figure 6: Ergonomic chair dimension for virtual reality system

3.7 Arm Support Dimension

The arm support (*as*) height is adjustable. It can accommodate 95% of the population from the shortest user to the tallest user in three positions, standing, sitting, sitting and standing position. Statistically, the arm support height dimension is in the range between 2.5th % tiles to 97.5th % tiles. The important body dimension on an adjustable arm support height design is shoulder height and shoulder elbow length in standing, shoulder height from seat, shoulder elbow length and popliteal height in a sitting. No allowance is provided.

The arm support dimension in standing position refers to Appendix and equation (8) for minimum and maximum height is 891.04 mm and 1058.64 mm. For sitting position based on equation (9) for minimum and maximum height are 538.16 mm and 666.76 mm. While dimension for the minimum arm support height in the sitting and standing position refers to the maximum arm support height in the sitting position (666.76 mm) and for

maximum arm support height in sitting and standing position refers to the minimum arm support height in the standing position (891.04 mm).

$$as\ (\min/\max) = sh\ (\min/\max) - sel\ (\min/\max) \quad (8)$$

$$as\ (\min/\max) = sh\ (\min/\max) - sel\ (\min/\max) + ph\ (\min/\max) \quad (9)$$

3.8 Lighting

Two cool white deluxe fluorescent lamps are used with an efficiency of 50–60 lumens/watt, color temperature 4100° K, and color rendering index of 85. The lamp was set at 3.25 m in height from floor and located on upper user.

The Cathode Ray Tube (CRT) display is used that also provides the light. The super video graphic array (SVGA) 25 inches produces a resolution 800 x 600 pixel. It was inclined at 45° from the worktable.

4. DISCUSSION

4.1 The uniform test and the adequate test

The uniformity test and adequate test for all the body dimensions, male and female, is described in Table 1. Results of the uniformity test show that all anthropometrics data is uniform. It means that there are no extreme body dimensions.

Results of the adequate or acceptance test, shows that the number of sample used for the entire body dimension, male and female, is acceptable. It means that the number of sample of anthropometrics data collected is adequate for the designing ErgoVR station.

4.2 Characteristic of ErgoVR Station Design

The concept of the adjustable design was applied to the worktable height, seat height and also backrest height. Adjustable dimensions of the worktable height for three positions used (standing, sitting and standing, and sitting) are in between 646.912 mm for minimum height and 1213.6 mm for maximum height with the minimum height of the worktable for standing position is 999.83 mm (Figure 2) and the maximum height for sitting position is 821.70 mm (Figure 3). While the dimension of the worktable height for sitting and standing position is in between 821.70 mm for minimum height and 999.83 mm for maximum height (Figure 4). Adjustable dimension of the worktable height on ErgoVr station can provide ease for user completing the task as well as avoiding excessive poor impact on the body muscles.

While concept of extreme design was applied to determine the width and length of worktable dimension and the width and depth of seat dimension. Figure 5 describes worktable width and length dimension. This worktable are 860.00 mm in width and 1.202.00 mm in length where the width is the 5th % tile of arm reaches forward length of smaller subject (female) and also the length was the 5th % tile of forearm-hand length and shoulder breadth of smaller subject (female). It means that the shorter user can reach object easily and comfortably such that the excessive poor impact on the arm and back muscle can be avoided.

For the width of seat was the 95th % tile of hip breadth of larger subject (female) that is 425.00 mm in width. It is required to accommodate the larger user for sitting comfortably. While the depth of seat is the 5th % tile of buttock to popliteal length of smaller subject (female). It is also required to accommodate a smaller user for sitting comfortably with no excessive pressure under thigh and buttock.

The arm support was required for three positions, standing, sitting, and sitting and standing. The concept of adjustable design and movable in rotation were applied to accommodate 95% of the shortest and the tallest user. The repetitive motion and virtual object were main cause of the musculoskeletal disorder. Thus it is important to reduce this incident by supporting the arm such that the excessive poor impact on arm and shoulder muscles can be prevented.

Appropriate dimensions of the ErgoVr station design to users will provide comfort to the user when interact with virtual object in the VR system. This is because the ErgoVr station used can alleviate those works stresses especially musculoskeletal disorders that adversely affect the health, safety and efficiency of users. Thus the users feel, see and interact with objects in the most natural and ergonomic position.

Use of CRT display is heavier than LCD display and gives higher resolution. Higher resolution causes the user to feel comfortable in completing a particular VE task. Goertz et al. (1995) reported that groups of new user of VR are disappointed with the low resolution of the display.

Fluorescent lamps are used because they provide a good combination of efficiency and color rendering properties (Sheedy, J.E, 2005). High luminance levels in the field of view create glare discomfort. Good lighting design can significantly reduce discomfort glare. By placing the lamp at upper of user and inclining the CRT display at 45° cause the light does not directly entering the eyes of the VR user so that it can prevent visual discomfort.

5. CONCLUSION

It can be concluded that:

1. The range of worktable height for three position used are in between 646.912 mm for minimum height and 1213.6 mm for maximum height.
2. The width and length of worktable are 860.00 mm in width and 1202.00 mm
3. The range of seat height for sitting position used is in between 371.00 mm for minimum height and 488.00 mm for maximum height

4. The width and depth of seat are 425.00 mm in width and 390.00 mm in depth
5. The range of backrest height from seat height for sitting position used is in between 217.16 mm for minimum height and 228.72 mm for maximum height
6. The range of arm support height for three position used are in between 538.16 mm for minimum height and 1058.64 mm for maximum height.
7. Use of CRT display causes the user to feel comfortable in completing a particular VE task as well as two cool white deluxe fluorescent lamps for lighting.

6. RECOMMENDATION

Cyber sickness is an undesirable side effect of virtual environment similar to motion sickness (La Viola, 2000). It is important to understand the factors that contribute to cyber sickness, in the hope of reducing its incidence.

Recommendation for future research is to investigate the effect of Ergonomics Virtual Reality station on incident of cyber sickness.

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APPENDIX

Appendix: Anthropometric Data in millimeter for the Malaysian adult population (mm)

Body Dimension Measurement	Male						Female					
	Mean	SD	2.50%	5%	95%	97.50%	Mean	SD	2.50%	5%	95%	97.50%
1: Body height	1629	65	1502	1522.1	1735.9	1756.4	1531	58	1417.3	1436	1626	1644.68
2: Shoulder height (standing)	1343	61	1223	1245	1438	1462.56	1257	51	1157	1188	1348	1356.96
3: Waist height (standing)	940	46	849.8	863	1008	1030.16	887	49	790.96	818	969	983.04
11: Shoulder breadth	425	28	370.1	386	472	479.88	403	39	326.56	356	471	479.44
12: Hip breadth	322	31	261.2	284	381	382.76	353	39	276.56	291	415	429.44
13: Arm reach forward length	822	50	724	765	887	920	767	39	690.56	710	829	843.44
14: Forearm-hand length	455	31	394.2	419	489	515.76	427	31	366.24	398	460	487.76
16: Buttock to popliteal length	435	48	340.9	402	478	529.08	437	46	346.84	380	536	527.16
19: Shoulder height from seat (sitting)	566	34	499.4	519	612	632.64	538	28	483.12	498	586	592.88
20: Shoulder elbow length	351	27	298.1	309	389	403.92	313	24	265.96	275	350	360.04
22: Popliteal height	391	24	344	354	428	438.04	370	25	321	342	416	419
26: Chest circumference	851	84	686.4	747	979	1015.64	868	91	689.64	757	1032	1046.36
27: Waist circumference	757	113	535.5	623	970	978.48	752	120	516.8	617	1008	987.2
29: Upper arm Circumference	257	29	200.2	218	308	313.84	257	37	184.48	209	321	329.52
Diameter of the proximal segment of forearm	81.85	9.24		69.43	98.1		81.85	11.78	58.752	66.56	102.2	104.943