The effect of sustained VDU and non-VDU near-work on visual acuity and refractive error in emmetropic and low-hyperopic primary school children

Swee Chai Teoh[1, *], Ai-Hong Chen[2] and Norhani Mohidin[3]
[1]School of Optometry, National Institute of Ophthalmic Sciences (academic arm of the Tun Hussein Onn National Eye Hospital), Petaling Jaya, Selangor, Malaysia
[2]Department of Optometry, Faculty of Health Sciences, Universiti MARA, Shah Alam, Selangor, Malaysia
[3]Department of Optometry, Faculty of Allied Health Sciences, National University of Malaysia, Kuala Lumpur, Malaysia

Abstract
Myopic shift in refraction following a sustained period of near-work is well documented among adult visual display unit (VDU) users. This crossover study investigates the effect of VDU near-work on visual acuity and refractive status among 7-year-old children. Thirty emmetropic and low-hyperopic schoolchildren (refractive error: -0.25DS to +1.25DS, astigmatism ≤ 1.00DC and anisometropia ≤ 1.00D) participated in this study. All subjects (15 males and 15 females) were involved in two 2-hour near-work sessions (at 40 cm), one with and one without a VDU, which were carried out in random sequence on two separate days. Distance visual acuity (monocular/binocular) and subjective refractive error were measured before and immediately after both near-work sessions. MANCOVA analysis showed that VDU work produced a significant myopic shift, -0.10 ± 0.18 D ($F_{1,54} = 5.17$, $p = 0.03$) in distance refractive status. This myopic shift was not found after non-VDU work. There was no significant change in monocular ($F_{1,54} = 0.03$, $p = 0.86$) and binocular visual acuity ($F_{1,54} = 0.22$, $p = 0.64$) after near-work with or without VDU. Emmetropic and low-hyperopic schoolchildren are susceptible to VDU near-work after-effect. Sustained VDU near-work causes significant myopic shift in emmetropic and low-hyperopic 7-year-old children. However, the myopic shift is not accompanied by a reduction in visual acuity.

Received December 4, 2011, accepted: May 3, 2012.
Key words: visual acuity, refractive error, visual display unit, myopia
Correspondence: scteoh_2002@yahoo.com

Introduction
The effect of VDU (visual display unit) use on distance visual acuity and refractive status has remained debatable due to inconsistencies in previous findings (Cole, Maddocks, & Sharpe, 1996; Gould & Grischkowsky, 1984; Haider, Kundi, & Weissenböck, 1980; Nyman, 1988; Piccoli, Braga, Zambelli, & Bergamaschi, 1996; Rey & Meyer, 1980; Yeow & Taylor, 1989). Studies involving experienced adult VDU users have demonstrated a significant myopic shift in refractive status after a full working day of VDU work (Gratton, Piccoli, Saniboni, Meroni, & Grieco, 1990; Haider et al., 1980; Rey & Meyer, 1980). This myopic shift in refraction has been described as the near-work induced transient myopia (NITM). The presence of this NITM was coupled with VDU users reporting blurred distance vision. However, the change in distance refraction was reversible (Haider et al., 1980) and the refraction returned to the pre-task level within 10 to 15 minutes. Changes in visual acuity and refraction were not observed in conventional office workers (Haider et al., 1980; Rey & Meyer, 1980).

Well controlled laboratory studies also reported significant changes in visual acuity (Gould & Grischkowsky, 1980) and distance refractive status (Owens & Wolf, 1987; Piccoli et al., 1996) with extended and continuous use of VDUs. Piccoli et al. (1996) found a myopic shift of -0.0356 D and -0.0359 D in the right and left eye respectively after 350 minutes continuous work with VDU. A similar group of workers demonstrated a lesser degree of myopic shift, -0.0137 D in the right eye and -0.0138 D in the left eye after working for a similar duration of time but on hard copy display (Piccoli et al., 1996). Piccoli et al. (1996) reported that different modes of near-work produced significantly different effects on distance visual acuity and refractive status. Later work reported significant myopic shifts in open loop conditions after sustained near-work with VDU displays (Owens & Wolf, 1987). An inward shift of the tonic accommodation position was postulated as the plausible mechanism contributing to the myopic shift following near-work (Owens & Wolf, 1987).

A longitudinal study also demonstrated a shift in refractive status towards myopia among adult VDU users (Cole et al., 1996). Subjects who worked with VDUs were -0.35 D ($p < 0.001$) more myopic than subjects who worked with hard copies. However, Cole et al. (1996) reasoned that the greater amount of myopia in the VDU group might be caused by over-accommodation induced by VDU work or a bias in self-selection, where the myopes displayed the same characteristics that led them to select, or be selected for, occupations that involved VDU use.

In contrast, several studies found no significant change in visual acuity and refractive status in experienced VDU workers (Nyman, 1988; Yeow &Taylor, 1989). Nyman (1988) reported that professions using VDUs did not display greater incidence of myopia compared to professions that did not use VDUs. The study by Yeow and Taylor (1989) supported the findings that continuous short term VDU work induced a statistically significant myopic shift (0.12 D, $p < 0.01$), the change was small and probably had no significant clinical effect on vision. Yeow and Taylor (1989) also noted that there was no significant difference in refractive changes between the VDU and non-VDU groups if the VDU was not used continuously. The number of hours spent on VDU work and the distribution of time spent were suggested to be the potential factors contributing to significant changes in refractive status (Yeow & Taylor, 1989).

To date, the effect of sustained VDU work on visual functions in the child population is not well studied. Children (aged between 5 and 12 years) were found to show similar amounts of accommodation adaptation as adults (aged between 22 and 30 years) when they were exposed to near-work (Rosenfield, Chiu, Ciuffreda, & Duckman, 1994). A recent study determining the visual activities engaged by children before the onset of juvenile myopia found that those who developed myopia had spent a greater number of hours per week undertaking near visual activities such as reading, using computers and playing video games (Jones et al., 2011). Furthermore, preschool- and schoolchildren aged between 5 and 12 years were reported to have larger heterophorias, reduced near point of convergence and reduced accommodation compared to children in child care centres who were not enrolled in the education system (Chen, O'Leary, & Howell, 2000). This pattern of change in visual function was suggested to result from greater involvement in near visual activities after enrolment in elementary education (Chen et al., 2000). Esophoria was identified as a risk factor in myopia progression (Chung & Chong, 2000). As near-work has been postulated to be associated with myopia progression (Ciuffreda & Vasudevan, 2008), and with young children spending an increasing number of hours on computer work, there is an urgent need to understand the effect of sustained VDU use in children.

The aim of this study was to compare the effect of 2-hour continuous near-work sessions, with and without a VDU, on distance visual acuity and refractive status in emmetropic and low-hyperopic schoolchildren using the crossover design. Normally, young children have minimum exposure to VDUs during their preschool years and the first year of primary school. Recruitment of this group of children eliminates a possible cumulative effect of previous VDU exposure to produce a reliable study outcome.

Methods

Thirty 7-year-old school children (15 males and 15 females) with parental consent participated in this study through random sampling. All subjects were emmetropic or had low hyperopia with spherical equivalent ranging from -0.25 D to +1.25 D, with astigmatism less than -1.00 DC, anisometropia less than 1.00 D and no history of ocular pathology or systemic disease based on the questionnaires distributed to their parents. All subjects had monocular and binocular corrected visual acuity of 6/6 or better with LEA Number Chart at 4 metres (illumination was 550-580 lux). This study adhered to the ethical standards of the Helsinki Declaration of 1975 and was approved by the Ethics Committee of The National University of Malaysia.

The subjects recruited for this study were all non-VDU users. Based on the questionnaires, all of the subjects spent less than 5 hours per week working on a VDU, at least for the past one year. According to classification by Saw, Nieto, Katz, and Chew (1999), only those who spent at least 5 hours on a VDU display every day were categorized as VDU users. Subjects with unaided monocular visual acuity worse than 6/6 were prescribed spectacles which were worn during near-work to avoid variation in accommodative demand between subjects.

The crossover study design compared the effect of near-work with and without a VDU on distance visual acuity and refractive status. The same subjects worked as the experimental group as well as the control group. The illumination of the experimental room was fixed between 300 lux and 380 lux (with Topcon Luxmeter). The illumination on the VDU display and print out copy was also monitored with a luxmeter at the beginning and at the end of every near-work session. Near-work sessions with and without a VDU were carried out on two separate days.

Each subject was assigned to play computer games (named VDU work) and visual searching tasks with printed copies on paper (named non-VDU work) in random sequence. The computer games were displayed on a desktop (NEC Powermate ML5). The illumination of the VDU display ranged between 300 lux and 380 lux, while the contrast and brightness of the display were fixed at 80% and 90% respectively to produce a luminance between 66 cd/m^2 and 70 cd/m^2 (Topcon Luminance meter BM-5). Games such as Virtual Cops 2, Tetris and Bomber Man 2 with great visual demand and visual searching activities were used as VDU related near-work to increase the demand of visual concentration. Meanwhile, the non-VDU work involved visual searching and drawing tasks, such as drawing a path through a maze, searching for words from a pool of alphabets, searching for differences in two pictures, joining dots, drawing and matching two similar pictures. Non-VDU work tasks were presented as black print on white paper, with the size of print ranging from 4 mm to 6 mm. Illumination on the printed copies was between 300 lux and 380 lux, which also produced an average luminance that ranged from 60 cd/m^2 to 70 cd/m^2.

Both VDU work and non-VDU work were carried out continuously for 2 hours at 40 cm. The VDU work and non-VDU work tasks both required great visual attention from the subjects (Jashcinski & Toenies, 1988; Rosenfield & Ciuffreda, 1994). To make the tasks even more interesting, the subjects were constantly given encouragement and were motivated with rewards at the end of the study if they showed good scores in both computer games and paper games. Both types of near-work were carried out in the same experimental room to avoid variation in room illumination and room setup.

Monocular visual acuity for right and left eye, binocular visual acuity and distance refractive error for both right and left eye were measured before and immediately after near-work sessions. Monocular (right eye and left eye) and binocular visual acuity was measured using LEA Number Chart at four metres. Chart illumination was always fixed between 550 lux and 580 lux (Bailey, 1998) and visual aquity was recorded in logMAR units (Cole et al., 1996). The distance refractive error was measured using standard subjective refraction techniques to determine the sphere and cylinder refractive error and the result was recorded as the spherical equivalent (D). The final prescription was determined by the maximum plus that gave the best visual acuity. During the post-task measurements, visual acuity and refraction were reassessed. The examiner was only provided with the subjects' pre-task prescription to avoid bias in the measurement.

The power of the measured variables was ranged from 85% to 100% with CCSTAT software. Data was analyzed with SPSS 15.0. A normality test showed that the data was normally distributed. A paired *t*-test was carried out to compare both pre-task readings which showed that monocular and binocular visual acuity and the refractive status were not significantly different before both near-work sessions were carried out ($p > 0.05$). Comparison of the visual acuity and refractive error between the right and left eye with unpaired t-test showed no significant difference ($p > 0.05$). Hence, analysis of the post-task measurement only took into account the right eye visual acuity, binocular visual acuity and the right eye spherical equivalent. The effect of near-work on post-task visual acuity and refractive error was analyzed with MANCOVA, with the pre-task visual acuity and spherical equivalent as the covariates. The dependent variables were the post-task visual acuity and spherical equivalent.

Results

The MANCOVA analysis showed that different modes of near-work produced a significantly different effect on post-task refractive error ($F_{1,54} = 5.17$, $p = 0.03$). Pairwise comparison of the refraction before and after near-work showed that sustained VDU work produced a significant myopic shift in distance refractive error (mean myopic shift: -0.10 ± 0.18 D). The same work duration with non-VDU work did not produce a significant myopic shift (0.00 ± 0.18 D) ($p = 0.03$) (Figure 1). The mode of near-work had no significant effect on the post-task measurement of monocular ($F_{1,54} = 0.03$, $p = 0.86$) and binocular visual acuity ($F_{1,54} = 0.22$, $p = 0.64$). Analysis of the covariates showed that pre-task refraction was significantly different from post-task refraction ($F_{1,54} = 116.52$, $p < 0.05$). Interestingly, pre-task monocular visual acuity was significantly different from post-task monocular visual acuity ($F_{1,54}$ =26.79, p < 0.05), whereas for binocular visual acuity there was no significant difference between the pre- and post-task readings ($F_{1,54}$ = 1.76, p = 0.19). The effects of near-work on refractive error and visual acuity were further confirmed by analyzing the changes found after the near-work sessions. This additional test was performed to avoid Type I error due to repeatedly comparing the dependent variables with their pre-task reading. The changes in visual acuity and refractive error were calculated by subtracting the pre-task reading from the post-task reading. For visual acuity, a negative value represents a reduction in visual acuity and vice versa. For refractive status, negative values represent myopic shifts, and positive values represent hyperopic shifts. A paired t-test showed that VDU work produced a statistically significant myopic shift in distance refractive error, but this was not the case with non-VDU work (t = -2.77, p = 0.02) (Figure 1). The change in astigmatism after near-work was also investigated by comparing the pre- and post-task astigmatism. A paired t-test showed that astigmatism was not significantly affected by near-work with and without VDU (p > 0.05). A paired t-test also showed that changes in monocular (t = -0.28, p = 0.78) and binocular visual acuity (t = 0.58, p = 0.57) were not significantly different between VDU work and non-VDU work (Figure 1).

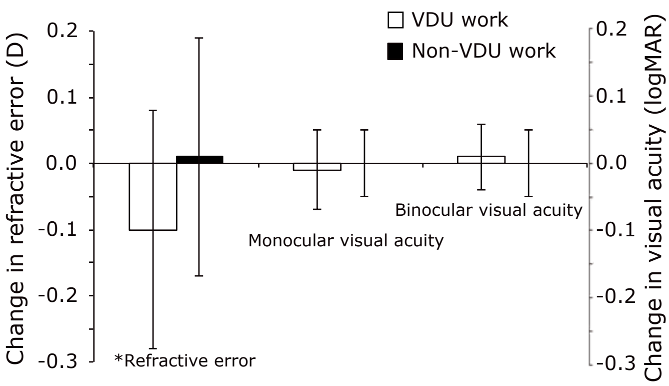

Figure 1. Comparison of the changes in distance refractive error, monocular visual acuity and binocular visual acuity after VDU work (open bars) and after non-VDU work (filled bars). Error bars represent standard deviation.
*p < 0.05

Discussion

A 2-hour session of sustained VDU work produced a statistically significant myopic shift (-0.10 ± 0.18 D) in distance refractive status under closed loop conditions. However, the change in refractive status was not accompanied by clinically measurable change in distance visual acuity in emmetropic and low-hyperopic children. In contrast, neither the refractive status nor the visual acuity showed significant change after non-VDU near-work in the same group of children (p > 0.05).

In this study, a relatively small amount of NITM was noted after two hours of continuous VDU work. This is consistent with previous reports (Owens & Wolf, 1987; Piccoli et al., 1996; Yeow & Taylor, 1989). A refractive change of -0.12 D had been reported in VDU users after 2.5 hours of continuous VDU near-work but not with 2 hours non-VDU work (Yeow & Taylor, 1989). The degree of myopic shift found in the present study is compatible with that reported in Yeow and Taylor's study (1989). Our study highlights that emmetropic and low-hyperopic young children who are inexperienced VDU users are just as capable of adapting to near visual stress as adult VDU users. Different modes of near-work apparently cause significantly different effects on the amount of NITM found in these young children. The question of interest is why there is a discrepancy in the amount of NITM induced by the different modes of near-work. In this study the same group of children performed both modes of near-work with exactly the same work paradigm to control the intra subject variable. The NITM found after VDU work must have persisted for at least 10 minutes, which was the duration of time required to perform the post-task visual acuity and refraction measurements. In contrast, NITM was not observed in the same group of children after non-VDU work.

Working with VDUs and conventional hard copy displays involves the adoption of different work postures. Variation in vertical inclination of gaze direction and working distance have been suggested to be associated with incidence of eyestrain among adult VDU users (Jaschinski, Heuer, & Kylian, 1998a; Jaschinski, Koitcheva, & Heuer, 1998b; Jaschinski, 2002). Jaschinski et al. (1998a) investigated the work posture of VDU users and reported that adult users preferred a working distance ranging from 60 cm to 100 cm and a vertical inclination of gaze direction ranging from horizontal to 16 degrees downwards. Variations from these preferred work postures were related to changes in oculomotor functions (Atchison, Claydon, & Irwan, 1994; Jaschinski et al., 1998b; Jaschinski, 2002; Takeda, Neveu, & Stark, 1992). Lowering the head position or increasing the vertical inclination of gaze direction were found to increase the accommodative response (Atchison et al., 1994; Takeda et al., 1992) and an inward shift in dark vergence and dark focus position (Jaschinski et al., 1998b). A closer dark vergence and dark focus position produced an advantage in near visual activities as it reduced the discrepancy between the resting position and the fixating target (Ebenholtz, 1985; Owen & Wolf, 1987). A greater dioptric difference between the resting position and the fixating target had been postulated to increase input from the parasympathetic system which in turn might inhibit sympathetic input during high cognitive demand (Chen, Schmid, & Brown, 2003; Ebenholtz, 1985; Rosenfield & Ciuffreda, 1994). As a result, continuous input from the parasympathetic system produced persistent contraction in the ciliary muscle even after termination of near-work, which was displayed as a myopic shift, or NITM was observed.

In this study, posture during near-work was photographed and the vertical inclination of gaze direction was determined from the photo by measuring the angle between horizontal to the middle of the display. The mean vertical inclination of gaze direction at 40 cm was -9.8 ± 5.6 degrees with VDU work and -30.3 ± 8.5 degrees with non-VDU work just before termination of near-work sessions. Greater downward gaze with non-VDU work might suggest a lesser accommodative effort was required during the course of near-work (Ebenhotz, 1984; Owen & Wolf, 1987). In contrast, lesser inclination direction during VDU work had been reported to show lower amplitude of accommodation and farther vergence and accommodation resting position (Jaschinski et al., 1998a,1998b; Owen & Wolf, 1987). This implies that a higher level of accommodative demand or greater parasympathetic innervation is required with VDU work. Therefore, it is not a surprise that a greater amount of NITM was noted in the present study.

The other difference between the VDU display and hard copy print out is the target content. The accuracy of accommodative response had been reported to vary with different spatial frequency profile (Strang, Day, Gray, & Seidel, 2011; Taylor, Charman, O'Donnell, & Radhakrishnan, 2009; Tucker & Charman, 1987). Mid spatial frequency (4 cpd) produced the most accurate accommodative response (smaller accommodation microfluctuations), while low and high spatial frequencies both produced a less accurate accommodative response (displayed as greater amount of accommodation microfluctuations) (Day, Strang, Seidel, Gray, & Mallen, 2006; Tucker & Charman, 1987). Greater accommodation microfluctuations were also observed with increased accommodative demand (Day et al., 2006). A previous study had reported greater accommodation microfluctuations with VDU work (Ukai, Tsuchiya, & Ishikawa, 1997) which implied indirectly that a greater accommodative effort was required while fixating at VDU display. If this is the case, VDU displays may consist of spatial frequencies which are less efficient stimuli to accommodation. Therefore, utilizing these spatial frequency profiles may require greater input from the parasympathetic system and create an imbalance in autonomic input that produces a greater amount of NITM with VDU work. Furthermore, VDU work in the present study involved computer games which require consistent visual tracking and change of fixation during the course of near-work, while paper games in non-VDU work may require less frequent change in fixation. However, this hypothesis may need further investigation.

In the present study, the NITM found after VDU work is not coupled with reduced distance visual acuity. As reported by Rosenfield (1998), the blur threshold in an emmetropic subject was ± 0.11 D. Studies of defocus and depth of focus have suggested that when blurriness in retinal image falls below 0.30 D, this will critically reduce the visibility of fine details on the retinal image and produce a larger error in accommodation response (Iwasaki, Tawara, & Miyake, 2005; Randle, 1988). In this study, the amount of NITM produced following VDU related near-work is about -0.10 D. This minor degree of myopic shift may be too small to create blurriness in the fine details of the retinal image as compared to the 0.30 D suggested by Randle (1988) and Iwasaki et al. (2005). Therefore, no clinically measurable reduced distance visual acuity was noted in present study.

The present study demonstrates that although emmetropic and low-hyperopic school children work continuously with VDUs at a relatively relaxed working distance, they are more susceptible to VDU near-work effect. Short term use of VDU is capable of producing -0.10 D NITM in emmetropic and low-hyperopic children. In long term use of VDU, the cumulative effect from sustained VDU near-work may produce a greater amount of NITM. The classical theory which associates NITM with myopia progression considers the presence of hyperopic defocus. With the presence of NITM, a smaller amount of accommodative response is required during near viewing. As a consequence, the focused image will always fall behind the retina. This condition produces a hyperopic defocus in the central as well as the peripheral retina, which in turn generates a signal to cause axial elongation. Eventually, the hyperopic defocus leads to myopia progression (Day & Duffy, 2011; Sng et al., 2011). Emmetropic school children who eventually became myopic showed hyperopic refraction at both nasal and temporal retinal locations up to 30 degrees eccentric to the fovea (Sng et al., 2011). Increased blur detection threshold (up to 1.25 D) with increasing eccentricity (up to 10 degrees from fovea) as a result of increased depth of focus (Charman & Radhakrishnan, 2010) may have caused the accommodation system to respond less accurately, which resulted in a greater amount of hyperopic defocus during the near-work. In this study, the small amount of NITM (-0.10 D) may not have produced enough hyperopic defocus to cause axial elongation. But, greater concern should be focused on the amount of the actual NITM and the role of this NITM in varying the hyperopic defocus in both the central and the peripheral retina during extended periods of near-work.

Considering that external factors such as vertical inclination of gaze direction and working distance may produce significant changes in visual functions and the link between NITM and myopia progression, it is crucial to design a proper and comfortable workplace for young VDU users. In the present study, the habitual workstation in a local primary school was used as the workstation for the VDU work and non-VDU work. The outcome from the present study suggests that the setup of the VDU workstation in the local primary school should be re-examined to ensure the suitability for young children. A properly designed workstation is essential to help in monitoring and controlling the progression of refractive anomalies in children.

Table 1: Mean refractive error (calculated in spherical equivalent), monocular visual acuity and binocular visual acuity before and after near-work with and without VDU

	VDU work		Non-VDU work	
	Pre-task (mean ± *SD*)	Post-task (mean ± *SD*)	Pre-task (mean ± *SD*)	Post-task (mean ± *SD*)
Refractive error (D)	+0.22 ± 0.33	+0.14 ± 0.29	+0.30 ± 0.31	+0.30 ± 0.30
Monocular visual acuity	0.03 ± 0.06	0.02 ± 0.07	0.03 ± 0.06	0.03 ± 0.06
Binocular visual acuity	-0.03 ± 0.05	-0.02 ± 0.05	-0.02 ± 0.06	-0.02 ± 0.05

SD = standard deviation. Visual acuity was measured in LogMAR.

doi:10.5384/SJOVS.vol5i1p22 – ISSN: 1891-0890

Conclusions

Two hours continuous VDU work at 40 cm produces a statistically significant myopic shift in distance refractive error without clinically measurable blurred distance vision. In comparison, continuous work with printed hard copies produces no statistically significant change in distance refraction or visual acuity.

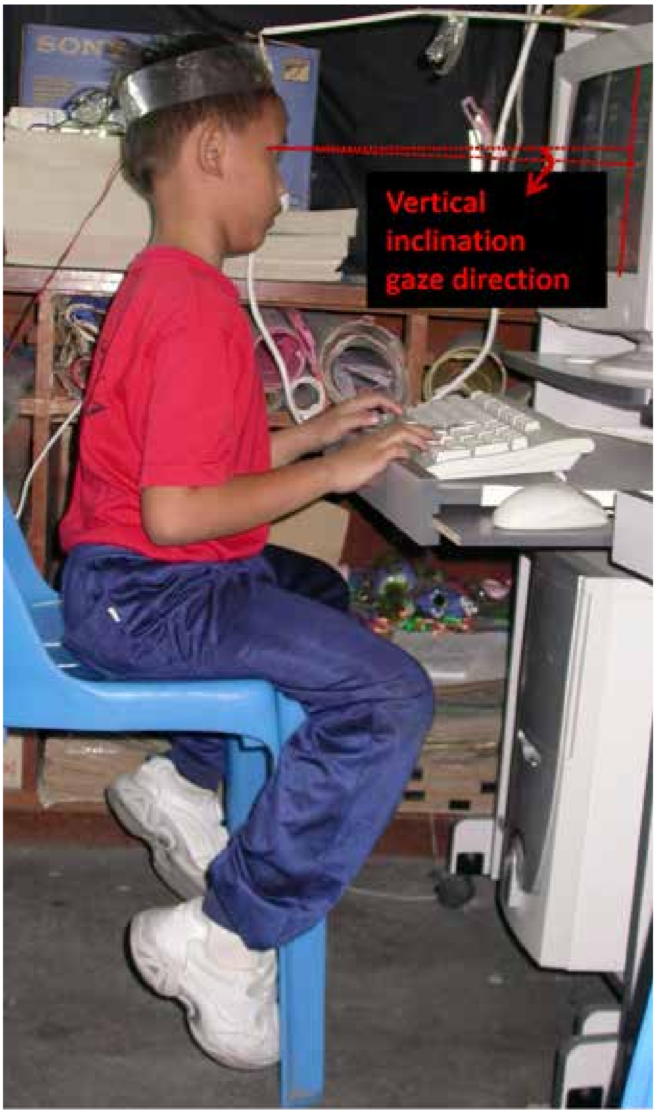

Figure 2. An example of VDU work station in the local primary school.

Acknowledgement

This study was carried out under IRPA Grant 02-02-0032-EA100.

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