A Psychophysical Approach to the Evaluation of Perceived Focusing Quality of CRT Displays

Kwang Ho Yoon[*b], Sang Ho Kim[a], and Sung Ho Chang[a]

Abstract

In this study, we collected data used to formulate the relationship between quantitative metrological parameters in CRT display and the perceived focus quality. Human perception of the focusing quality was evaluated in terms of user feedback scores regarding the character legibility from four highly trained inspectors. Thirteen CRT monitors from five different manufacturers were compared relatively with respect to the norm monitor. The profile of electron beam such as spot size and the shape of distribution made by electron beam, contrast, convergence of RGB beams, and luminance characteristics were measured using a precision measurement system. Linear regression analysis and artificial neural network models were used to formulate the relationship between human perception and the quantitative measurements. The accuracy of the formulated linear regression model (R^2 = 0.515) was not satisfactory but the nonlinear neural network model (R^2 = 0.716) was fairly convincing and robust even the utilized data included subjective differences.

Keywords : CRT, perceived focusing quality, linear regression analysis, neural network model

1. Introduction

The keen market competition of CRT displays with colour and higher resolution has caused a corresponding increased emphasis on improved measurement of their focusing capabilities. Part 3 of the ISO 9241 series (1992) addresses the ergonomic requirements for the visual displays in office work situations, but there have been numerous debates and criticisms on this standard. Besuijen and Spenkelink (1998) argued that the standard was more engineering than ergonomic. They also addressed problems of this standard in relations to the system configuration, software applications, display settings, user behaviour, wear and physical environments. There would be great discrepancy and disagreement when comparing displays measured using different techniques or expressed in different forms. Different test operator perception and skills will further add to the problem and this in turn will not represent the human perception of image quality.

It is well known that the focusing capabilities of CRT displays affect the perceived sharpness or legibility of the characters reproduced on it. Hence, there is a critical need for the display companies to evaluate or quantify, if possible, the human perception about character legibility using the data obtained from direct measurement of quantitative parameters rather than asking for individuals. These data is expected to be very useful to development engineers for not only predicting the effects of design or redesign but also for prioritizing their actions on the basis of marginal contribution to the perceived image quality. Measurable quality parameters will provide a good way to address customer needs and a vehicle for making inevitable compromises between cost and performance in a sensible and rational way.

The main objective of this study is to suggest a psychophysical approach for formulating the relationship between quantitative metrological parameters in CRT display and the perceived focusing quality reproduced on it.

2. Materials and Methods

2.1 Selection of quantitative parameters

Prior to conducting the experiments, we first conducted literature surveys and discussions to identify the quantitative

Manuscript received July 7, 2004; accepted for publication September 16, 2004.
This study is supported by Center for Research of High Quality and Automated Processes in Electronic Parts Industry in Kumoh National Institute of Technology that is assigned by Korea Science and Engineering Foundation.
[*]Members, KIDS.
Corresponding Author : Sang Ho Kim
a. Department of Industrial and Systems Engineering, Kumoh National Institue of Technology, 188 Shinpyung-dong, Gumi, Gyeongbuk 730-701, Korea.
b. LG.Philips Diplays, 184 Gongdan 1-dong, Gumi, Gyeongbuk 730-030, Korea
E-mail : kimsh@kumoh.ac.kr **Tel** : +54 467-4387 **Fax** : +54 467-4476

parameters surrounding the focus quality of CRT displays. Among the various parameters related to the focus quality of CRT displays, profile of the electron beam, convergence, contrast, and luminance were selected as the major influencing factors which can be measured reliably using the current state of the metrological instruments. The electron beam profile means that three-dimensional shape of luminance intensity made by the electron beam on the spot of CRT screen and it used to follow a Gaussian distribution. The convergence was measured as the sum of rectilinear distances among RGB spot centers. To express the electron beam profile using a few measurable quantities, the twelve parameters summarized in Table 1 were introduced in this study. The electron beam profile was measured using ADI 5200 from ADI systems. Fig. 1 presents the definitions of the eccentricity and the slope graphically.

Table 1. Quantitative parameters measured for quantifying the electron beam profile

Notation	Definition
H_A , H_B	Horizontal diameter of the cross-section at 10 % (A) and 50 % (B) cutting planes of the electron beam
V_A , V_B	Vertical diameter of the cross-section at each cutting plane of the electron beam
$Size_A$, $Size_B$	The cross-sectional area at each cutting plane of the electron beam (= H+V/2)
H/V_A , H/V_B	The ratio of H and V (which indicates the rate of ovalness of the electron beam)
SH_{BA}, SV_{BA}	The horizontal and vertical slopes between the two cutting planes A and B
AR_{BA}	The ratio of $Size_A$ and $Size_B$
X_{BA}	Eccentricity between the centroids from the two cutting planes A and B.

2.2 Experiment

In this study, thirteen 19" CRT monitors made by five different manufacturers, which are currently available in the market, were used. All the monitors were set at horizontal and vertical frequency of 91 kHz×85 Hz, screen resolution of 1280×1024, luminance of 30 foot-lamberts, colour temperature of 9300 Kelvin. All of the quantitative parameters, except for contrast were measured from evenly distributed nine points at a monitor. Contrast was measured at raster center under its best condition.

Human perception of the focusing quality was evaluated in terms of feedback score regarding the legibility of English characters "H" and "e" from four highly trained field inspectors. Prior to conducting the experiment, a norm monitor with the best focus quality among the utilized monitors was drawn unanimously by all inspectors. The perceived character legibility scores of the norm monitor were evaluated by the inspectors on the basis of one's own preference with a maximum scale of 100 points. Each monitor was then compared one by one with the norm monitor using the inspector's own subjective scale. All monitors were presented twice to an inspector. The order of presentation was fully randomized.

3. Results

3.1 Normalization of the PCLS

The perceived character legibility scores (PCLS) of the monitors were different in their mean and dispersion for each inspectors. This result shows that there existed some subjective differences in appraisal standard among the inspectors. To resolve this problem, the raw

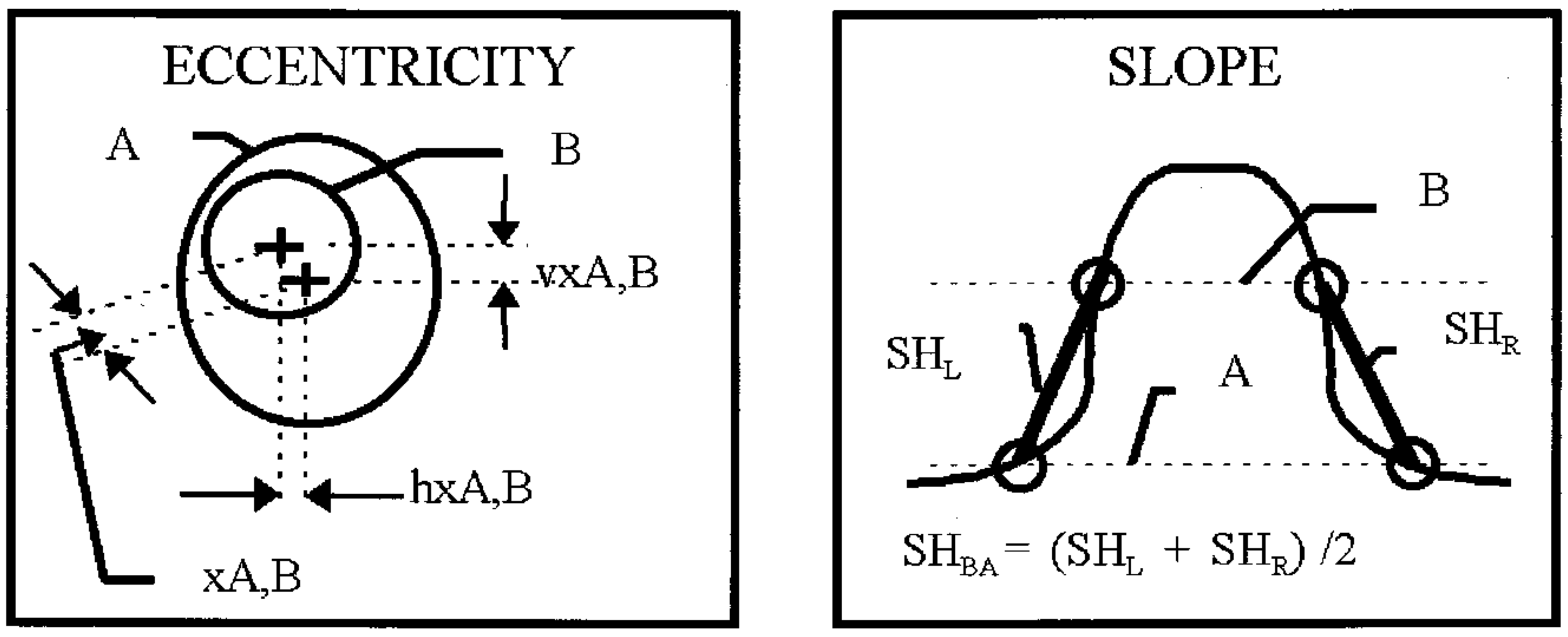

Fig. 1. Graphical representations of the eccentricity (X_{BA}) and the slope (S_{BA}).

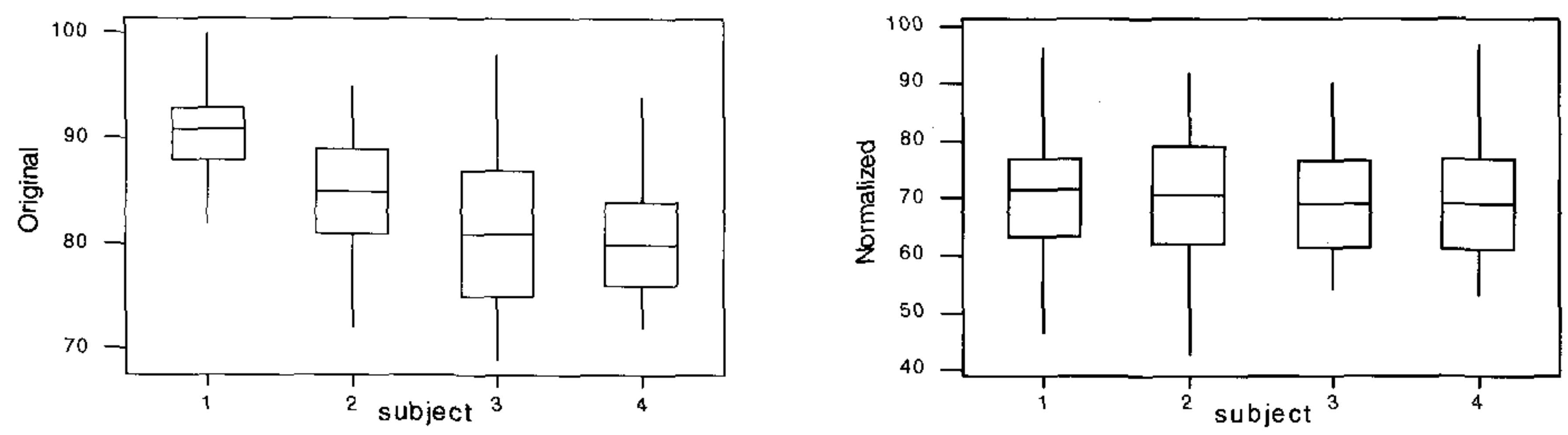

Fig. 2. PCLS before and after normalization.

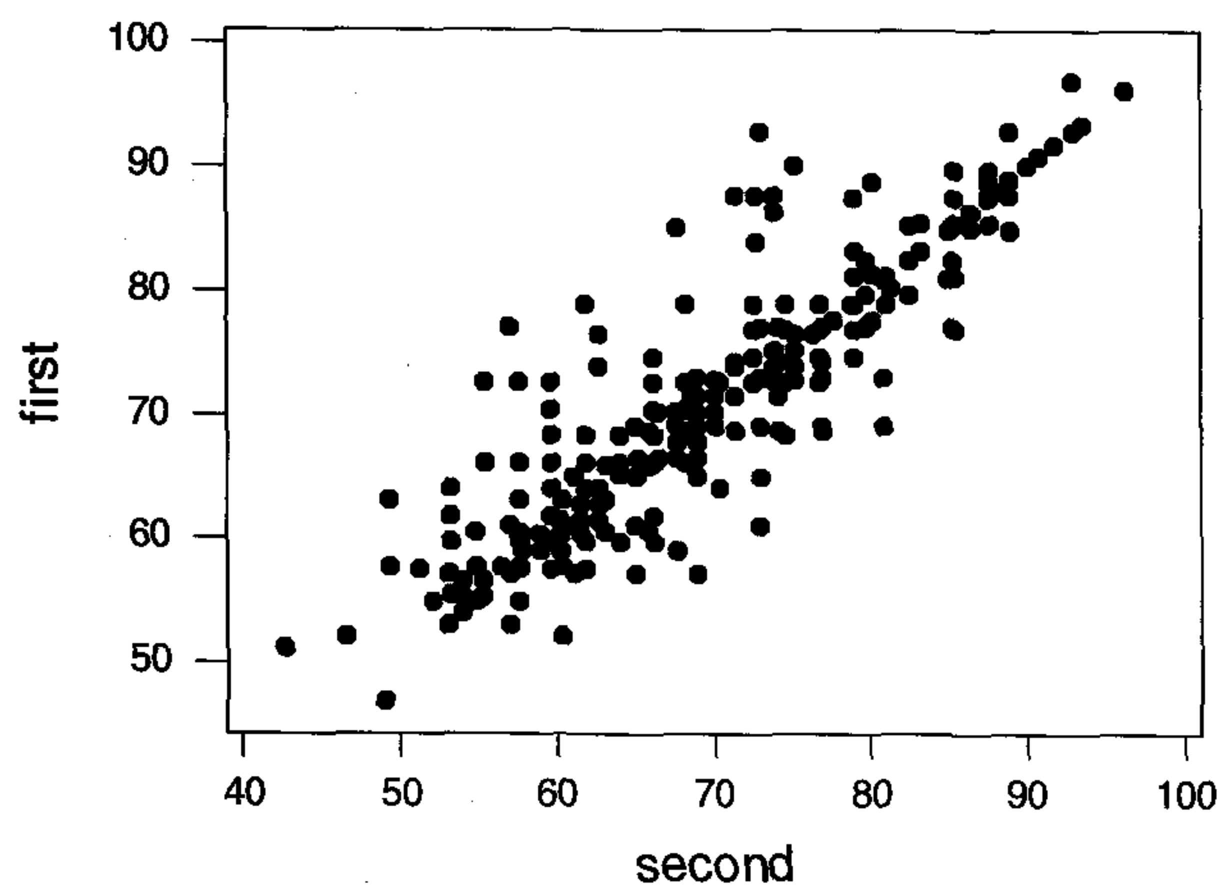

Fig. 3. Correlation of PCLS between 1st and 2nd trial.

scores from one inspector were studentized by their respective mean and standard deviation. The studentized scores were then transformed to a normally distributed variable with a mean of 70 and a standard deviation of 10. Fig. 2 illustrates the original and the normalized values of PCLS.

To validate the subjective rating and normalization procedure for evaluating the perceived focusing quality, repeatability and reproducibility of the procedure were tested as follows. To validate the repeatability (consistency of the results within each inspector), correlation analyses and paired-t comparisons were conducted on the scores and their ranking obtained at first and second trial within each inspector (see Fig. 3). The correlation coefficient of scores and ranking between the first and second trial was 0.907 and 0.915, respectively. There was no statistical difference in the scores and ranking between each trial (p-value = 0.99 and 1.0). These results indicate that the inspectors had fairly consistent subjective rating standard for their own and that this procedure can be applied repetitively for assessing perceived focusing quality.

To validate the reproducibility (coincidence of the results between inspectors), correlation analyses and paired-t comparisons were also conducted on the scores obtained from the different inspectors. The correlation coefficients in scores between pairs of inspectors were ranged from 0.570 to 0.785 (see Table 2). The result shows that there existed some subjective differences in the preference but the differences were not statistically significant.

Table 2. Correlation coefficients in PCLS between pairs of inspectors

r	Inspector 1	Inspector 2	Inspector 3
Inspector 2	0.785		
Inspector 3	0.724	0.593	
Inspector 4	0.628	0.570	0.683

3.2 Multiple linear regression analysis

A multiple linear regression analysis was conducted to formulate the relationship between the quantitative measures of display quality and the PCLS. To check the multi-collinearity among the quantitative measures, a correlation analysis was preceded. The result showed that fairly high correlations existed among the twelve parameters introduced to characterize the electron beam profile. A factor analysis to resolve the multi-collinearity was conducted and the results showed that the twelve parameters can be grouped into four factors (F1~F4). Factor 1 (F1) was highly correlated with vertical diameter of the electron beam, and thus V_A, V_B, H/V_A, H/V_B and SV_{BA} belonged to the group. Factor 2 (F2) was highly correlated with horizontal diameter of the electron beam, and thus H_A, H_B, $Size_A$ and $Size_B$ belonged to this group. The parameters closely related with horizontal shape of electron beam, SH_{BA} and AR_{BA}, were grouped into Factor 3 (F3). The eccentricity between two centroids of cross-sections A and B, X_{BA}, was classified as Factor 4 (F4) because it was not correlated with other parameters. The values of new variables F1 through F4 were obtained by the following conversions after standard normal transformation of each original variable.

$$Factor1 = -0.207(V_A) + 0.246(H/V_A) - 0.183(V_B) + 0.221(H/V_B) - 0.192(SV_{BA})$$
$$Factor2 = 0.260(H_A) + 0.185(Size_A) + 0.257(H_B) + 0.208(Size_B)$$
$$Factor3 = -0.564(SH_{BA}) + 0.571(AR_{BA})$$
$$Factor4 = X_{BA}$$

The following regression equation was derived from the multiple regression analysis (see Table 4) for the PCLS with seven independent variables, the four factors from factor analysis(F1~F4), contrast, convergence and luminance. The coefficient of determination (R^2) for the equation was 0.515, which indicates that linear model is not a good fit to formulate the relationship between the PCLS and the quantitative parameters.

$$PCLS=67.31-1.616(F1)-1.926(F3)-10.32\,(Convergence) + 0.279(Contrast)$$

Table 3. Rotated factor loadings and communalities using varimax rotation

Variable	Factor1	Factor2	Factor3	Communality
H_A	0.103	0.959	-0.019	0.931
V_A	-0.917	0.369	-0.049	0.980
$Size_A$	-0.541	0.819	-0.044	0.965
H/V_A	0.949	0.202	0.069	0.946
H_B	0.067	0.955	0.002	0.916
V_B	-0.848	0.385	-0.131	0.885
$Size_B$	-0.398	0.875	-0.068	0.930
H/V_B	0.835	0.336	0.131	0.828
SH_{BA}	0.036	0.400	-0.869	0.917
SV_{BA}	-0.813	0.273	0.041	0.737
AR_{BA}	0.188	0.246	0.880	0.871
Variance	4.3226	4.0011	1.5798	9.9035
% Var	0.393	0.364	0.144	0.900

Table 4. Results from stepwise regression analysis

Step	1	2	3	4
Constant	70.61	70.61	75.04	**67.31**
Factor 1	-1.892	-1.788	-1.723	**-1.616**
T-value	-44.47	-43.86	-43.31	-37.94
Factor 3		-1.840	-1.868	**-1.926**
T-value		-17.82	-18.70	-19.35
Converge			-9.99	**-10.32**
T-value			-14.01	-14.54
Contrast				**0.279**
T-value				6.59
S	7.89	7.48	7.23	7.17
R-square	41.34	47.30	50.75	**51.50**

3.3 Artificial neural network model

An artificial neural network model was used to formulate nonlinear relationship between the quantitative parameters and the PCLS. The architecture of neural network utilized in this study had a feed-forward backpropagation network with 7 input, 35 hidden and 1 output layers trained by a scaled conjugate gradient learning rule. The network was trained using two types of input data sets. In the first data set, seven input data was identical to those utilized in the former regression analysis. In the second data set, F1 through F4 were replaced with the original measured values of V_A, H_A, AR_{BA} and X_{BA}, which showed relatively high factor loading scores (see Table 3) among each group.

Among all of the data obtained from the experiment, 3/4 was used as training set and 1/4 was used as test set. The coefficient of determination for the network after 30,000 epochs of training was 0.716 for the first (transformed by factor analysis) data set and 0.711 for the second (original) data set, respectively. Fig. 4 illustrates the fitness of predicted PCLS of the network on the measured

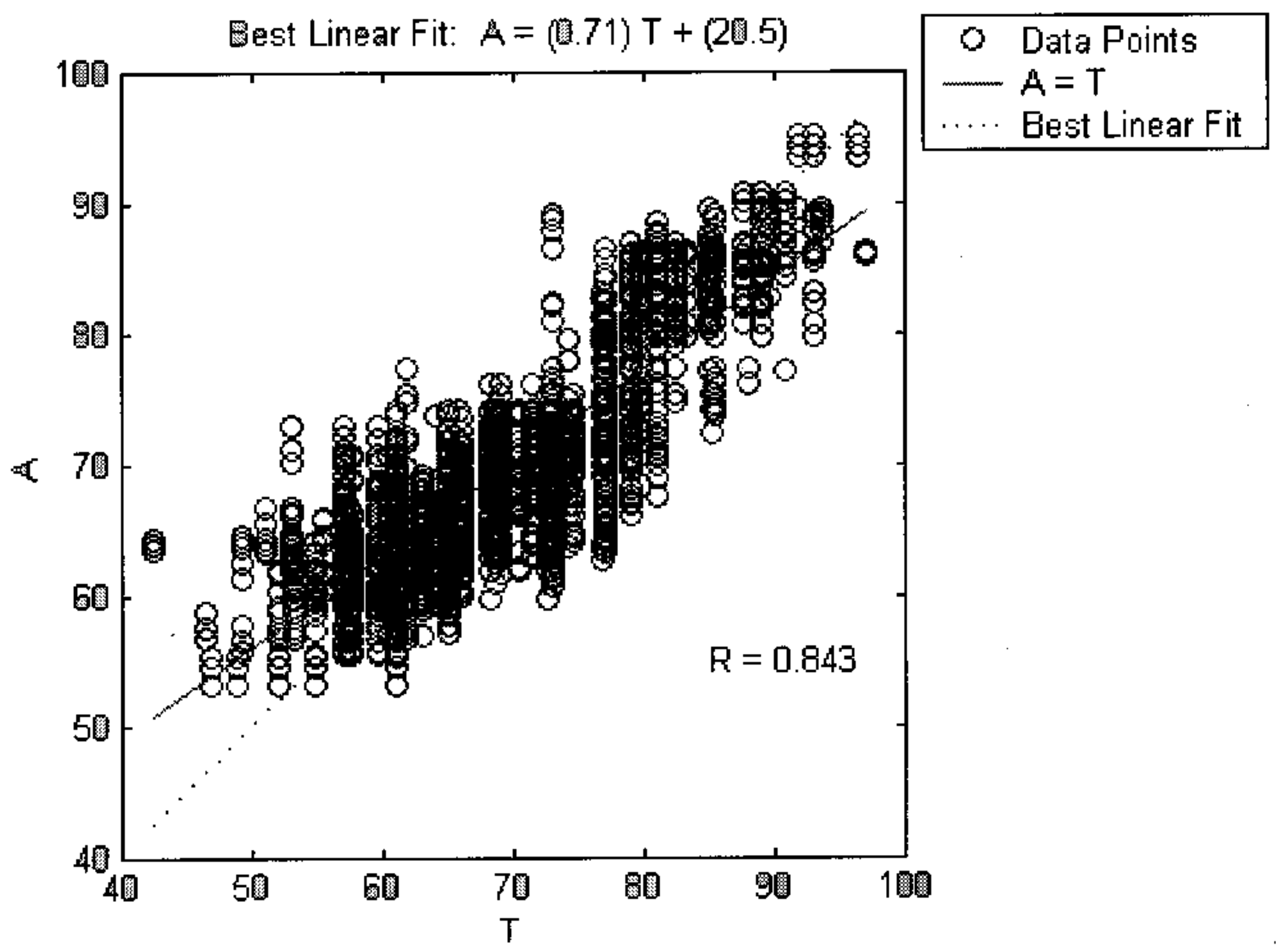

Fig. 4. Fitness between the predicted and the measured.

PCLS from the experiment.

In order to quantify the influences of quantitative parameters on the PCLS, the changes in the PCLS according to the parametric changes were analyzed using the developed network model. Fig. 5 illustrates the changing patterns of the PCLS with respect to the quantitative parametric changes.

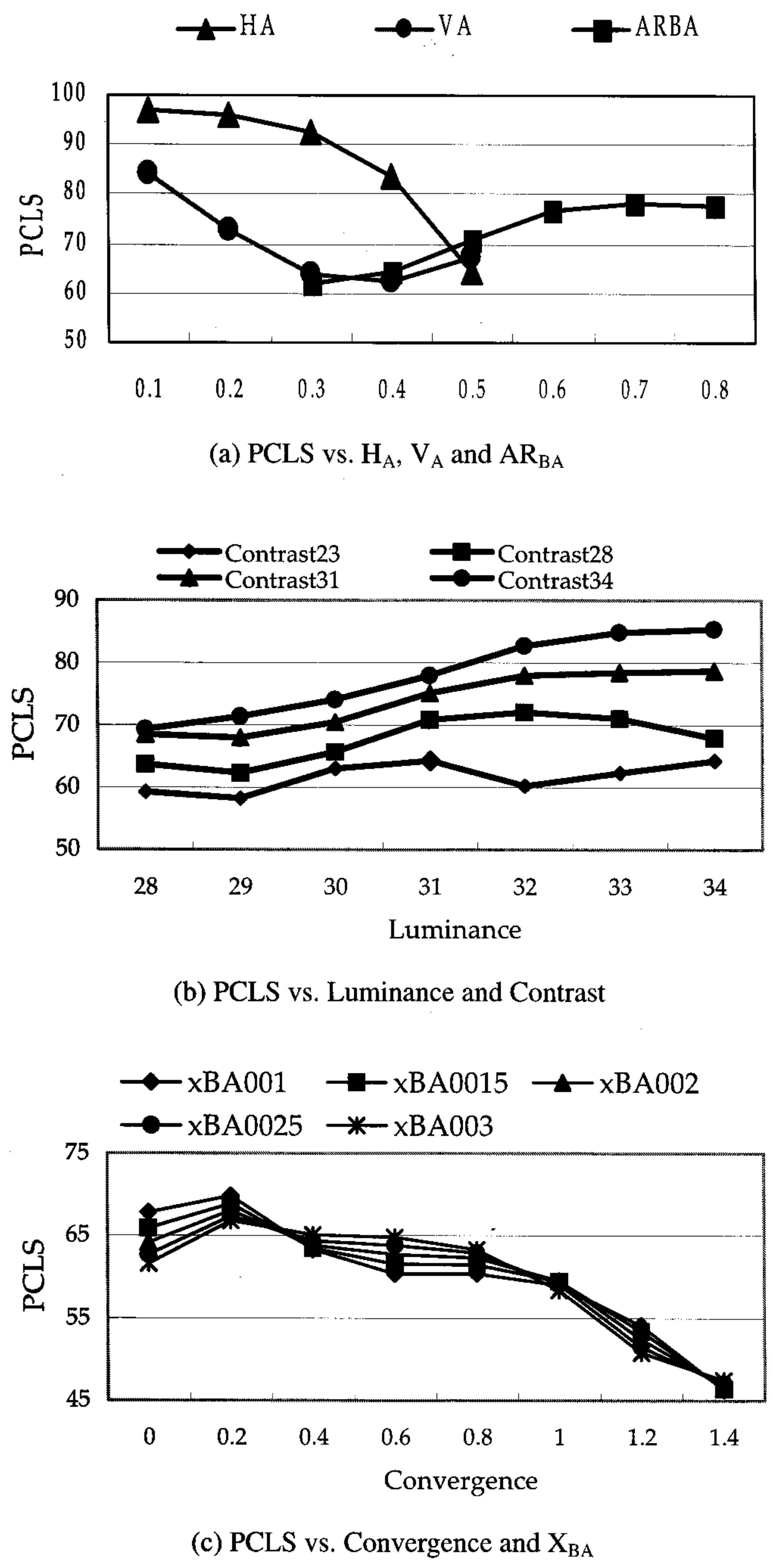

Fig. 5. Changes in PCLS with respect to the quantitative parametric changes.

4. Discussion

4.1 Subjective ratings for the PCLS

A subjective rating method using a norm monitor and a normalization procedure were introduced in order to quantify the perceived character legibility of CRT displays in this study. The validity of the procedure was substantiated by the fact that the procedure yielded repetitive and reproducible scores even though subjective differences cannot be excluded completely. It is expected that the PCLS of CRT displays obtained from asynchronous assessments can be used to compare on the basis of identical scale if the experiments utilize a unified norm monitor.

4.2 Formulation of the relationship

The results from statistical analyses, including correlation and multiple linear regression analysis, indicate that the PCLS is affected by the horizontal diameter, ratio between cross-sectional areas of the electron beam, convergence, and contrast. The low coefficient of determination in the linear model (0.515) seems to indicate that the PCLS is a nonlinear function of the quantitative parameters.

When the artificial neural network modeling approach was applied to formulate the nonlinear relationship, the coefficient of determination increased to 0.715, which seems quite a satisfying and convincing result considering that subjective differences are embedded in the PCLS data. The robustness of the neural network modeling approach was substantiated by the fact that the networks trained with two different kinds of input data sets produced similar level of prediction accuracy. Therefore, the raw data can be used as direct input to the network without transforming it by the factor analysis.

The major findings on the relationship between the quantitative parameters and the PCLS from this study can be summarized as follows:

1) As the horizontal and vertical diameters of the electron beam increase, the PCLS decreases nonlinearly.

2) As the ratio of cross-sectional areas increases, the PCLS increases nonlinearly.

3) As the luminance increases, the PCLS increases nonlinearly, and the influences of luminance become stronger under high contrast conditions.

4) As the convergence degrades, the PCLS decreases

nonlinearly.

4.3 Limitations and further research

To resolve the subjective difference issue among tester's perception in the evaluation of the focusing quality of CRT displays, we suggested a psychophysical approach to formulate the relationship between quantitative metrological parameters and the perceived quality. The neural network modeling approach showed quite a convincing and robust result for predicting the perceived focusing quality with a few metrological variables.

Although the procedures and results seemed very plausible, this study hads several limitations. The relationship between the quantitative metrological parameters and the perceived focusing quality cannot be interpreted as a causal relationship, because the data utilized in this study was obtained from a "quasi-experiment". Thus, there are other extraneous variables that could influence these results.

As the neural network models are merely fitting the networks of inputs to output for a given data set, they do not provide any logical reasoning or explanation for those relationship. In other words, the solution they provide is a good fit only for the given data set. Thus the scope of the experiment should be expanded to assure the external validity of this study.

References

[1] ADI 5200 Q&A, http://www.adisystem.com/products/adi5200.htm.

[2] Besuijen K. and Spenkelink G.P.J., *Displays* **19,** 67 (1998).

[3] Infante, C., *SID Seminar Lecture Notes **M-3,*** 1 (1995).

[4] ISO 9241-3, Visual display terminals used for office tasks-ergonomic requirements Part3: Visual display requirements (1992).

[5] Wanda, J.S., ISO and ANSI ergonomic standard for computer products: a guide to implementation and compliances (Prentice Hall, New Jersey, 1996).