Factors that are related to reduced visual acuity in male junior high school students and their effects: findings based on cross-sectional study

Yuuzaburou KABA*, Atsushi KAWAGUCHI2* and Takashi YANAGAWA2*

Objectives The study was performed to find factors in daily routines and living environments of male junior high school students that are linearly or non-linearly related to reduced visual acuity and to assess the strength of their relationships.

Methods Data on daily routines and living environments were collected by questionnaire from 382 male junior high school students and these data are matched with records on visual acuity of each student measured at the annual school medical examinations. In addition to univariate statistical analysis, multivariate analysis was conducted by the spline logistic regression developed in this paper by modifying the similar technique for follow-up studies; the detail of the method is given in the appendix of this paper.

Results A significant association was found between "viewing distance from a TV" and "reduced visual acuity" ($P=0.004$). There was also a significant interaction observed between "viewing distance from the TV" and "hair-obstructed eyes" ($P=0.012$). Furthermore, it was found that the adjusted odds ratio between the "reduced visual acuity" and "having 1～2 days of physical activity per week" relative to "having physical activity less than one day per week" was 0.27, which was statistically significant ($P=0.022$). While the adjusted odds ratio continued to decrease as the physical activity increased per week, this was not significant as compared to "having physical activity 1～2 days per week" ($P=0.204$).

Conclusions Exercising 1～2 days per week outside of school can prevent reduced visual acuity. In addition, students should be encouraged to prevent hair from obstructing their eyes and they should view TV from a distance of more than 2.5 m, as such behavior can prevent reduction in visual acuity.

Key words：visual acuity, male junior high school students, spline, logistic model, cross-sectional study

I. Introduction

The percentage of male junior high school students with unaided visual acuities of less than 1.0 has been increasing in the recent past. Surveys conducted in Japan over the past three years has found that the value is now around 50%.[1] Matsumura and Hirai (1999),[2] conducted surveys in 1984 and 1996 and found an increase of the incidence of myopia among individuals who were aged 10 years and older. Reduced visual acuity in children is of concern not only in Japan but also around the world and several studies have been conducted to determine responsible factors. Quinn et al. (1999),[3] Zadnik et al. (2000),[4] and Goto and Takano (2005)[5] focused on the impact of lighting, while Morioka et al. (1997)[6] and Furuta, Furuta and Miyao (2000)[7] studied the influence of growth in height. Marumoto et al. (1997)[8] examined the impact of the studying position and Hashimoto et al. (1998)[9] studied the influence of facial muscle weakness and masticatory performance. Several investigations have also been carried out looking at viewing distance from a TV, time spent watching TV, sleeping, studying, using a PC or playing computer games, reading books, and the number of days per week engaged in physical activity.[7,10～15] Other studies have reported influences of VDT work,[16] and genetic factors (family background) on the progress of myopia in young people.[15] These studies, however, did not provide any concrete evidence that could be used to prevent myopia.

We here conducted a cross-sectional study to find factors in daily routines and living environments of male junior high school students and to assess their effects. After adjusting for the influence of the other factors and taking into account the possible non-linear

* Kurume University Graduate School of Medicine (Doctoral Course in Biostatistics)
2* Biostatistics Center, Kurume University
Yuuzaburou KABA
Kurume University School of Nursing
777-1 Higashikushihara-Machi, Kurume-City Fukuoka 830-0003, Japan

relationship, we used spline logistic regression to assess the effects of the factors with reference to reduced visual acuity.

II. Methods

1. Subjects of the study

A total of 411 boys from 2 municipal junior high schools in Fukuoka Prefecture took part in the study. In April of 2005, questionnaires were distributed to every student with the help of "yogo" teachers ("nurse-teachers" who specialize in school health). Visual acuity of each student was obtained from the records of annual school medical examinations conducted about one week after the distribution of the questionnaire. After excluding those students who did not take the medical examination, those who did not complete the questionnaire, and those with ophthalmologic disease, amblyopia or allergic conjunctivitis, a total of 382 students (92.9%) were enrolled in the study. This group was composed of 124, 115, and 143 students in the first, second, and third grades, respectively. There were 171 students with "reduced visual acuity" and 211 with "normal vision". "Reduced visual acuity" and "normal vision" are defined in the section that follows.

2. Overview of the survey

1) Survey items

To minimize the possibility of bias introduced by ambiguously defined expressions or study items, we carefully designed the questionnaire with help from the "yogo" teachers and others involved with the students. In addition, the design of the questionnaire incorporated information from a surveillance program that monitored the health status of school children,[17] along with information from the annual report of physical and mental health among children.[18] The factors that we considered to be potentially related to the reduced visual acuity included: use of spectacles or contact lenses by parents and siblings; time spent per day using a PC or playing computer games, watching TV, studying at home or at a cram school, reading, and sleeping; days engaged in physical activity outside school per week; viewing distance from a TV; angle from which subjects watched TV; working under inadequate lighting; study location; presence or absence of stiff shoulder; how well a student's table and chair fit at school; presence or absence of obstruction of the eyes by hair; masticatory performance; food preference; and the intake of food such as noodles and green or yellow vegetables.

2) Method for measuring visual acuity

Landolt's broken ring chart[19] is the global standard for measuring visual acuity. In the current study, the chart indices used were 1.0, 0.7, and 0.3. To measure visual acuity, the ring chart with each index was shown to a student three different times with each viewing lasting for 3 seconds. If the student could correctly recognize 2 or more of 3 charts on the same index, this index was assigned as the subject's visual acuity.

3) Definition of terms

When visual acuity of either one or both eyes was less than 1.0, or if the subject wore spectacles/contact lenses, the individual was defined as having "reduced visual acuity". If the visual acuity was found to be 1.0 in both eyes during their annual examination and the subject did not use spectacles/contact lenses, the individual was defined as having "normal vision". "Working under inadequate lighting" refers to whether studied or read or not in an environment for which lighting was needed. "Study location" refers to whether or not subjects used a desk that was specifically designed for the purpose of studying, while "masticatory performance" refers to how well an individual chewed his food.

3. Ethical considerations

Prior to initiation of the study, the junior high school faculty examined and then approved the research protocol. The study design and questionnaire was also reviewed and approved by the Ethical Committee on Medical Service of Kurume University.

4. Methods of analysis

1) Covariates

Among the factors studied, 11 were dichotomous and 7 categorical. After taking into account the data size and number of parameters involved in the model that we employed, we selected 4 out of the 11 dichotomous factors for analysis. The other 7 dichotomous factors that were not selected had P-values larger than 0.3 in the univariate analysis (see Table 1). The factors selected for analysis were as follows: use of spectacles/contact lenses by parents or siblings ($X_8=1$, yes; $X_8=0$, no), presence of a hair-obstructed eye ($X_9=1$, yes; $X_9=0$, no), working under inadequate lighting ($X_{10}=1$, yes; $X_{10}=0$, no), and angle involved when watching TV ($X_{11}=1$, oblique; $X_{11}=0$, direct). All of the categorical factors were used in the analysis and included: viewing distance from the TV ($X_1=1$, <1.5 m; $X_1=1.5$, 1.5～2.0 m; $X_1=2.0$, 2.0～2.5 m; $X_1=2.5$, ≥2.5 m), time spent watching TV per day ($X_2=1$, <2 hours; $X_2=2$, 2～3 hours; $X_2=3$, 3～4 hours; $X_2=4$, 4～5 hours; $X_2=5$, ≥5 hours), days per week engaged in physical activity ($X_3=0$, <1 day per week; $X_3=1$, 1～2 days per week; $X_3=2$, 3～4 days per week; $X_3=3$, ≥5 days per week), time spent studying per day ($X_4=0$, <1 hour; $X_4=1$, 1～2 hours; $X_4=2$, 2～3 hours; $X_4=3$, ≥3 hours), time spent sleeping per day ($X_5=6$, <7 hours; $X_5=7$, 7～8 hours; $X_5=8$, 8～9 hours; $X_5=9$, ≥9 hours), time spent using a PC or playing computer games per day ($X_6=0$, <1 hour; $X_6=1$, 1～2 hours; $X_6=2$, 2～3 hours; $X_6=3$, ≥3 hours), and time spent reading per day ($X_7=0$, <1 hour; $X_7=1$, 1～2 hours; $X_7=2$, ≥2 hours).

2) Statistical analysis

In addition to the univariate analysis we conducted multivariate analysis. In particular, we used a spline

Table 1　Results of univariate analysis

Factors	Level	Normal vision	Reduced visual acuity	Odds ratio	95%CI	*P* value
Use of spectacles/contact lenses by parents or siblings	No	86(63.2%)	50(36.8%)	1.00		
	Yes	125(50.8%)	121(49.2%)	1.67	1.08–2.56	0.020
Working under inadequate lighting	No	131(51.8%)	122(48.2%)	1.00		
	Yes	80(62.0%)	49(38.0%)	0.66	0.43–1.01	0.058
Hair-obstructed eye	No	164(57.3%)	122(42.7%)	1.00		
	Yes	47(49.0%)	49(51.0%)	1.40	0.88–2.23	0.154
Viewing angle of TV	Direct	70(59.8%)	47(40.2%)	1.00		
	Oblique	141(53.2%)	124(46.8%)	1.31	0.84–2.04	0.231
Study location	No	118(53.6%)	102(46.4%)	1.00		
	Yes	93(57.4%)	69(42.6%)	0.86	0.57–1.29	0.464
Fit of table and chair at school	Yes	160(54.2%)	135(45.8%)	1.00		
	No	51(58.6%)	36(41.4%)	0.84	0.52–1.36	0.470
Masticatory performance	Good	90(53.9%)	77(46.1%)	1.00		
	Poor	121(56.3%)	94(43.7%)	0.91	0.61–1.36	0.642
Intake of noodles	<3 days per week	155(56.0%)	122(44.0%)	1.00		
	≥3 days per week	56(53.3%)	49(46.7%)	1.11	0.71–1.75	0.645
Stiff shoulder	Absence	84(54.2%)	71(45.8%)	1.00		
	Presence	127(56.0%)	100(44.0%)	0.93	0.62–1.40	0.735
Intake of green and yellow vegetables	≥3 days per week	159(54.8%)	131(45.2%)	1.00		
	<3 days per week	52(56.5%)	40(43.5%)	0.93	0.58–1.50	0.776
Food preference	No	33(54.1%)	28(45.9%)	1.00		
	Yes	178(55.5%)	143(44.5%)	0.95	0.55–1.64	0.845
Viewing distance from TV				0.70	0.47–1.03	0.068
Time spent watching TV				0.84	0.73–0.97	0.019
Physical activity per week				0.80	0.65–0.98	0.029
Time spent studying				0.96	0.78–1.17	0.650
Time spent sleeping				1.24	1.02–1.51	0.029
Time spent using a PC or playing computer games				0.94	0.77–1.15	0.568
Time spent reading				1.16	0.88–1.53	0.293

logistic regression modeling technique analysis described below in order to adjust for the influence of confounding factors. This made it possible to examine and elucidate the potential non-linear relationship between factors and reduced visual acuity. Kawaguchi et al. (2008) has recently developed a spline modeling technique that can be used to determine hazards ratios in follow-up studies.[20] Since the probability of response in general is a measure of a target in cross-sectional studies, we modified the method for use in cross-sectional studies by replacing the hazard ratio with a logit transformation of the probability of response and represented it by spline functions. We call it the spline logistic regression model. Kawaguchi et al. employed the Cox partial likelihood in estimating parameters of spline functions, but our modification required development of an estimation method of parameters of spline functions based on likelihood functions constructed from binominal distributions. The spline logistic regression model used in the analysis is a semi-parametric model that contains the main and interaction terms, and prespecified knots. The unknown parameters in the model are the coefficients and knots. Model selection technique such as the Akaike Information Criterion (AIC), and the Wald and Rao statistics were applied in the current analyses in order to select significant parameters of the model. Details of this method are illustrated in the Appendix. The LOGIS-

TIC procedure of SAS Version 9.1 was used to perform the analysis. Results were considered to be statistical significant when two-sided $P<0.05$.

III. Results

1. Univariate analysis results

Table 1 shows odds ratios, 95% confidence intervals, and *P*-values obtained from the univariate analysis.

2. Spline logistic regression model results

Table 2-1 lists the estimates of the parameters that were chosen by the model selection technique, along with their standard errors and *P*-values. Table 2-2 lists the adjusted odds ratios, 95% confidence intervals and *P*-values of the factors that had no significant interactions with any of the other factors. Table 2-3 lists values for the factors that did exhibit significant interactions. Examining the results given in these tables, we were able to obtain the following findings.

1) Viewing distance from a TV

A significant association was found between the "viewing distance from the TV" and the "reduced visual acuity" ($P=0.004$). There was also a significant interaction observed between the "distance from TV" and "eyes obstructed by hair" ($P=0.012$). Based on these findings, we assessed the relationship between the "viewing distance from the TV" and the "reduced visual acuity" separately. Figure 1 shows the relationship between the subject's "distance from the TV" (horizontal axis) and the probability of "reduced visual acuity" (vertical axis). The figure also indicates that for cases where there was obstruction of the eye by the subject's hair, there was an increased probability of reduced visual acuity as the viewing distance from the TV increased. The adjusted odds ratio was 2.11 for the "viewing distance from the TV" (≥2.5 m vs. <1.5 m). In contrast, this was reversed in cases where there was no obstruction of the eye by the hair, with an adjusted odds ratio of 0.32 when the "viewing distance from the TV" was ≥2.5 m vs. <1.5 m.

2) Time spent watching TV

Figure 2 presents the profiles of the adjusted odds ratios (vertical axis) between the "reduced visual acuity" and the "time spent watching TV" (horizontal axis) with respect to "watching TV less than 2 hours per day". As seen in the figure, a non-linear relationship was present. More precisely, there was a significant decrease ($P=0.009$) in the adjusted odds ratios for the "time spent watching TV 2～3 hours per day" relative to "watching TV less than 2 hours per day". In addition, there was also a decrease in the adjusted odds ratios for the "time spent watching TV more than 3

Table 2-1 Results from the spline logistic regression

Factors	Estimate	Standard Error	*P* value
Viewing distance from TV (X_1)	−0.75	0.26	0.004
Time spent watching TV (X_2)	−0.92	0.35	0.009
$(X_2-2)_+$	0.80	0.41	0.049
Use of spectacles/contact lenses by parents or siblings (yes) (X_8)	0.56	0.24	0.021
Physical activity per week (X_3)	−1.30	0.57	0.022
$(X_3-1)_+$	0.98	0.59	0.096
Time spent studying (X_4)	−0.68	0.31	0.027
$(X_4-1)_+$	0.86	0.40	0.032
Hair-obstructed eye (yes) (X_9)	−1.64	0.83	0.048
Working under inadequate lighting (yes) (X_{10})	−3.24	1.80	0.072
Viewing angle of TV (oblique) (X_{11})	−3.54	2.00	0.077
Time spent sleeping (X_5)	−0.43	0.25	0.080
$(X_5-8)_+$	1.02	0.44	0.021
X_1 and X_9	1.25	0.49	0.012
X_5 and X_{11}	0.41	0.24	0.095
X_5 and X_{10}	0.38	0.25	0.123
X_3 and X_{11}	0.41	0.28	0.136

Hosmer and Lemeshow Goodness-of-Fit Test $P=0.894$

$(X_2-2)_+$, $(X_3-1)_+$, $(X_4-1)_+$, and $(X_5-8)_+$ are basis function of spline logistic regression. For example, $(X_2-2)_+$ shows a positive part of X_2-2, that is, $X_2-2=0$ if $X_2<2$.

Table 2-2　Adjusted odds ratios obtained from Table 2-1

Factors	Adjusted odds ratio	95%CI	*P* value
Watching TV 2～3 hours per day	0.40[a]	0.20-0.80	0.009
Watching TV more than 3 hours per day	0.89[b]	0.73-1.10	0.296
Use of spectacles/contact lenses by parents or siblings (yes)	1.74	1.09-2.80	0.021
Physical activity 1～2 days per week	0.27[c]	0.09-0.83	0.022
Physical activity more than 3 days per week	0.73[d]	0.45-1.18	0.204
Studying 1～2 hours per day	0.51[e]	0.28-0.93	0.027
Studying more than 2 hours per day	1.19[f]	0.87-1.62	0.272
Working under inadequate lighting (yes)	0.04	0.00-1.33	0.072
Viewing angle of TV (oblique)	0.03	0.00-1.46	0.077
Sleeping 7～8 hours per day	0.65[g]	0.40-1.05	0.080
Sleeping more than 9 hours per day	1.80[h]	0.89-3.65	0.105

a. Relative to time spent watching TV less than 2 hours per day
b. Relative to time spent watching TV 2～3 hours per day
c. Relative to physical activity less than 1 day per week
d. Relative to physical activity 1～2 days per week
e. Relative to studying less than 1 hour per day
f. Relative to studying 1～2 hours per day
g. Relative to sleeping less than 7 hours per day
h. Relative to sleeping 8～9 hours per day

Table 2-3　Adjusted odds ratios obtained from Table 2-1

Hair-obstructed eye (X_9)	Viewing distance from TV (X_1)	Adjusted odds ratio	95%CI	*P* value
No	＜1.5 m	1.00		
No	1.5～2.0 m	0.68	0.53-0.89	
No	2.0～2.5 m	0.47	0.28-0.78	0.004(a)
No	≧2.5 m	0.32	0.15-0.70	
Yes	＜1.5 m	1.00		
Yes	1.5～2.0 m	1.28	0.84-1.95	
Yes	2.0～2.5 m	1.64	0.71-3.82	0.249(b)
Yes	≧2.5 m	2.11	0.59-7.46	

(a), (b); *P*-values of the slopes from linear regression

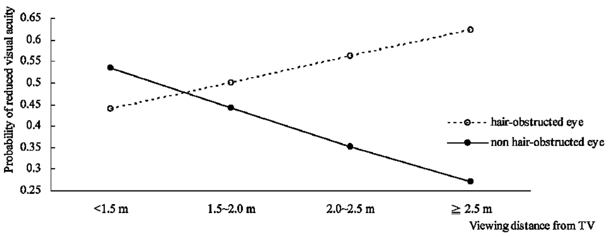

Fig. 1　Relationship between "viewing distance from TV" and probability of "reduced visual acuity"

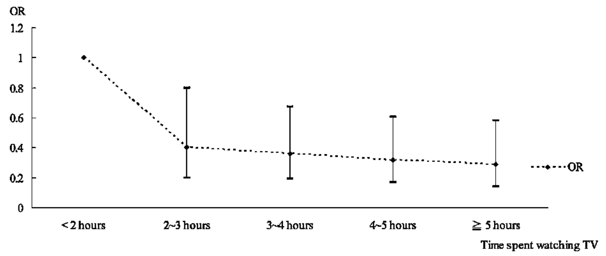

Fig. 2　Adjusted odds ratios between "reduced visual acuity" and "time spent watching TV" with 95% confidence intervals

hours per day" relative to "watching TV 2～3 hours per day", although this difference was not significant ($P=0.296$).

3)　Use of spectacles/contact lenses by parents or siblings

The adjusted odds ratio between the "reduced visual acuity" and the "use of spectacles/contact lenses by parents or siblings" relative to those who did not was 1.74 and was statistically significant ($P=0.021$).

4)　Days engaged in physical activity per week

Figure 3 presents the profile of the adjusted odds ratios (vertical axis) between the "reduced visual acuity" and the "days engaged in physical activity per week" (horizontal axis) with respect to "having physical ac-

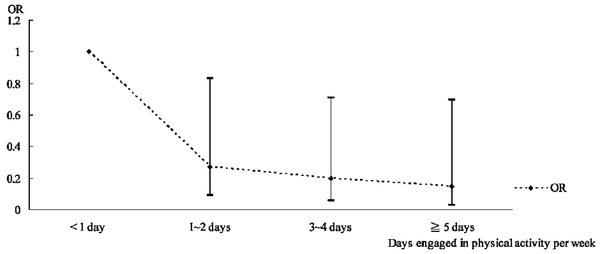

Fig. 3 Adjusted odds ratios between "reduced visual acuity" and "days engaged in physical activity" with 95% confidence intervals

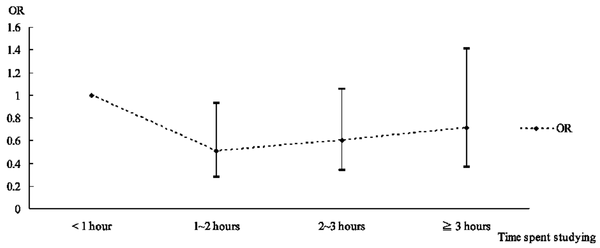

Fig. 4 Adjusted odds ratios between "reduced visual acuity" and "time spent studying" with 95% confidence intervals

tivity less than one day per week". The figure indicates that physical activities prevented reduced visual acuity. The adjusted odds ratio between the "reduced visual acuity" and "having 1～2 days physical activity per week" with respect to "having physical activity less than one day per week" was 0.27, and was statistically significant ($P=0.022$). The figure also shows that the adjusted odds ratio continued to decrease with increases in the physical activity per week, although without significance ($P=0.204$) when compared to those subjects that took part in "physical activity 1～2 days per week".

5) Time spent studying

Figure 4 presents the profile of the adjusted odds ratios (vertical axis) between "reduced visual acuity" and "time spent studying" (horizontal axis) with respect to "studying less than 1 hour per day". The figure indicates that there was a significant adjusted odds ratio of 0.51 ($P=0.027$) between "reduced visual acuity" and "studying 1～2 hours per day" with respect to "studying less than 1 hour per day". These values gradually increased as the amount of time spent studying also increased. However, these results did not prove to be significant when compared with values for "studying 1～2 hours per day" ($P=0.272$).

IV. Discussion

The spline logistic regression modeling used in the present paper employs model selection techniques and may be able to determine whether a relationship is linear or non-linear based upon data and also may estimate the strength of this relationship. Although in general spline logistic regressions are applied to continuous variables, in this study they were applied to categorical variables by using the first order spline functions that corresponded to the ordinal line regressions. The difference between our spline method and line regressions is in the selection of knots; the algorithm developed in the present paper makes it possible to select knots and interaction terms by using AIC, Wald and Rao statistics.

If non-linear factors are identified before a study, then dummy variables may be introduced into a conventional logistic regression in order to accommodate non-linearity. If one does this, the same results as were reported for the present model in this study should be found. However, when it is not possible to identify non-linear factors before the study, then a total of 21 dummy variables need to be introduced. This in turn will generate 304 parameters in the model that contain interaction terms. Based on the size of data set, 382, in the present study, this would mean that estimated parameters have substantial bias, and that a new model selection technique such as developed in this paper is necessary to avoid this bias.

Figures 2, 3 and 4 show the superiority of the spline logistic modeling as compared to conventional logistic modeling. As seen in the figures, we were able to detect non-linearity of the adjusted odds ratios by using the model selection techniques of the new method to fit the spline functions to the data, an action that is not possible when using the conventional logistic model. Figures 2, 3 and 4 also show that significant decreases of the adjusted odds ratios followed by non-significant mild decreases or increases were observed when using the new method. If conventional linear logistic regression were to be applied to the same data, there would be attenuation of the slopes of the linear odds ratios, and the slopes then become non-significant.

First, we discuss the relationship between "time spent watching TV" and "reduced visual acuity". It was found that the adjusted odds ratio for "reduced visual acuity" of students "watching TV 2～3 hours per day" relative to "watching TV less than 2 hours per day" was 0.40 ($P=0.009$). Additionally, the adjusted odds ratio continued to exhibit similar levels even if the time spent watching TV was longer than 2～3 hours per day. The univariate analysis results presented in Table 1 also support this finding, which was contradictory to our prestudy speculations, as we had assumed that shorter times spent watching TV would prevent reduction in visual acuity. However, it should be noted that ophthalmologists, school teachers, or their parents continually provide students with health guidance, such as not watching TV for more than two hours, which ultimately helps them avoid reduction in their visual acuity. Thus, this may be the reason why our original speculations were incorrect. In fact, when we specifically looked at those students who watched less than 2 hours of TV, we found that 76% of them were considered to have good health behavior, namely, they spent less than 3 hours per day using a PC or playing computer games and they watched TV from a distance of more than 1.5 m. It is reasonable to assume that the odds ratios for watching TV longer than three hours per day would have similar values to those who watched TV 2～3 hours per day, as students that watch TV more than three hours per day do not necessarily concentrate on the TV during the entire time, and thus the burden of eyestrain would be negligible. The current literature also is not strongly against our findings. For example, results with the multivariate logistic regression model used by Furuta, Furuta and Miyao[7] led to them to conclude that the risk for progression of myopia among male junior high and high school students tended to decrease with increase in the amount of time spent watching TV, although their findings were not statistically significant.

Second, we discuss the relationship between the "days engaged in physical activity per week" and "reduced visual acuity". When students who did not participate in physical exercise were compared to those who exercised 1～2 days per week, the adjusted odds ratio was 0.27 ($P=0.022$). This adjusted odds ratio maintained similar levels even when the amount of exercise was more than 2 days per week. The results thus indicate that exercise performed 1～2 days per week is enough to prevent reduced visual acuity. Ishii[21] studied male and female junior high school students and reported that reduced visual acuity incidence was higher among students who belonged to arts-oriented clubs that lacked physical activity than in those students who took part in vigorous physical activity. Ueno[22] studied male elementary school students and showed that individuals with a rich experience in sports had better vision as compared to those that did not. Eguchi and Wakabayashi[23] studied male and female elementary and junior high school students and reported that the incidence of myopia was almost twice as high in a group of children that played indoors as compared to a group that played outdoors. They emphasized the necessity of playing outdoors in order to help release tension from children's eyes. Mutti et al.[15] studied male and female students whose average age was 14 years old and reported that the adjusted odds ratio of "myopia" with respect to "an 1-hour increase per week" was 0.917. When we used the data from Table 2-1 to compute the adjusted odds ratio for students who watched TV from an oblique angle and who exercised 3～4 days per week, we calculated an odds ratio of 0.46. It should be noted that in the present study, 70% of all students watched TV from an oblique angle. If we assume that a student exercises for two hours per day for four days, based on the study by Mutti et al., the adjusted odds ratio for those undertaking exercise each week can be assessed to be $(0.917)^{2\times4}=0.50$, which is close to the value that we found after adjusting for confounding factors. Our results indicated that in order to prevent reduced visual acuity, subjects needed to exercise 1～2 days per week. However, it should be noted that greater amounts of physical exercise per week do not increase the effectiveness.

Third, we discuss the relationship between "time spent studying" and "reduced visual acuity". The adjusted odds ratio of the visual acuity with respect to "spent studying for 1～2 hours" relative to "spent studying less than one hour" was 0.51 ($P=0.027$), which indicates that studying for 1～2 hours significantly decreases the number of those students with reduced visual acuity as compared to those that study less than one hour. However, since in general it is assumed that fatigue of the eyes leads to reduced visual acuity, one has to question the verity of these results. Once again, the reason why these results were found could be due to a limitation of the study, i.e., students who study for 1～2 hours everyday could have a stronger discipline that could afford them a healthier life style as compared to those students who study less than an hour. Unfortunately, the current study was not designed to clarify this. Of course, the intuitive relation is followed if time spent studying is longer. Figure 4 shows that there was an increase in the values of the adjusted odds ratio beyond the point seen for those who spent 1～2 hours studying. While the increase per unit category was 1.19, this value was not significant ($P=0.272$). Furuta, Furuta and Miyao[7] estimated the adjusted odds ratios and found for male junior high and high school students that studying for two or more hours significantly increased the reduction in visual acuity as compared to studying for less than 1 hour. Marumoto et al.[8] studied male and female students whose average age was 13 years old and suggested there was a possible relationship between visual acuity and bad posture during studying. However, the current study did not examine this possible relationship.

Fourth, we discuss the relationship between "use of spectacles/contact lenses by parents and siblings" and "reduced visual acuity". We found there was a significant association between these factors for our subjects ($P=0.021$), in line with findings of several previous studies[10,15] of male and female students of various age groups. It should be noted that the "use of spectacles/contact lenses by parents and siblings" is related not only to heredity, but also to living conditions, habitat and environment. Therefore, in order to be able to estimate these effects with the least amount of bias, it was important to adjust our analyses for the latter in the present study.

Fifth, we discuss the relationship between the "viewing distance from a TV" and "reduced visual acuity". There were no knots selected for this factor in the spline logistic regression modeling and the relationship proved to be linear. When we examined eyes that were not obstructed by hair, the adjusted odds ratio for the distance from the TV ≥2.5 m vs. <1.5 m was calculated to be 0.32 ($P=0.004$). This indicates there was a significant decrease in reduced visual acuity as the viewing distance from the TV increased. Arita et al.[10] studied male elementary and junior high school students and found that there was a larger number of individuals with reduced visual acuity when they watched TV from a distance less than 1 m versus those who watched from a distance greater than 1 m. Misawa, Shigeta and Nojima[11] examined the distance from the TV while playing video games and found similar results with male elementary school students. When studying this association, it might be important to take into account the exposure to low-frequency electromagnetic waves that emanate from the cathode-ray tube (CRT) screen of the TV. In fact, other studies[24,25] examined the impact of low-frequency electromagnetic waves from CRT screens at the cellular level in mice and established that there were corneal disorders and lens opacity after the exposures. Further research will need to be performed in the future in order to study the influence of low-frequency electromagnetic waves in humans.

As seen in Figure 1, there was a significant interaction between the "distance from the TV" and "obstruction of the eye by a subject's hair" ($P=0.012$). Figure 1 shows that the above findings hold true for students in which the hair did not obstruct the eyes. However, for the students with hair-obstructed eyes, the probability of reduced visual acuity increased as the distance from the TV increased. In other words, there is an increased effect on reduced visual acuity as the viewing distance from the TV increases. It has been suggested that having long hair that hangs over the eyes can lead to a reduction in visual acuity due to eyestrain that is caused by this impaired visibility or by the continuous corneal stimuli. It would not be unreasonable to expect that the former students would have more chance of eyestrain and thus, a reduced visual acuity because of the increased difficulties they encounter while trying to watch the TV screen. At the present time, there has been no research conducted that has studied the interaction between "TV viewing distances" and "hair-obstructed eyes". Our current finding supports the arguments that have been made at schools and potentially provide us with a new insight on the relationship between "TV viewing distances" and "reduced visual acuity".

Finally, we ask the readers to carefully interpret the values of the adjusted odds ratios that are presented in Table 2-2. In particular, adjusted odds ratios for the "viewing angle of the TV" and "working under inadequate lighting" are 0.03 and 0.04, which are very small. When stratified adjusted for the data by the other factors we found that the numbers of data fell in cells were very small and that this made the values of the odds ratios unstable. Since these odds ratios are not significant we should not interpret them.

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APPENDIX　Spline logistic regression model

1) Model

Consider n independent individuals with data (Y_1, X_1^*), (Y_2, X_2^*), …, (Y_n, X_n^*), where Y_i is a binary response variable and X_i^* is L dimensional covariates vector of the i-th individual. We apply the following first order spline logistic regression model to the data:

$$\log \mathrm{it} P(Y=1|X^*) = \ln \frac{P(Y=1|X^*)}{1-P(Y=1|X^*)} = \alpha(X^*),$$

where $X^* = (X_1, X_2, \ldots, X_L)$ and $\alpha(X^*)$ is given by

$$\begin{aligned}\alpha(X^*) = \beta_0 &+ \sum_{l=1}^{L} \beta_l X_l + \sum_{l=1}^{L_1}\sum_{m=1}^{M_l} \beta_{lm}(X_l - r_{lm})_+ \\ &+ \sum_{l_1=1}^{L-1}\sum_{l_2=l_1+1}^{L} \beta_{l_1 l_2} X_{l_1} X_{l_2} \\ &+ \sum_{l_1=1}^{L}\sum_{l_2 \neq l_1}^{L_1}\sum_{m=1}^{M_{l_2}} \beta_{l_1 l_2 m} X_{l_1}(X_{l_2} - r_{l_2 m})_+ \\ &+ \sum_{l_1=1}^{L_1-1}\sum_{l_2=l_1+1}^{L_1}\sum_{m_1=1}^{M_{l_1}}\sum_{m_2=1}^{M_{l_2}} \beta_{l_1 l_2 m_1 m_2}(X_{l_1} - r_{l_1 m_1})_+ \\ &\times (X_{l_2} - r_{l_2 m_2})_+,\end{aligned}$$

where $(x)_+ = x$ if $x>0$ and 0 otherwise, r_l's are knots relevant to the variable x_l, β's are the unknown regression parameters, X_1, …, X_L are the covariates, L_1 is the number of categorical variables, and M_l is the number of knots to be estimated from the data. Note that in the present data $L=11$ and $L_1=7$. The likelihood function is easily constructed by incorporating the spline logistic regression model and the regression parameters are estimated by maximizing the likelihood function by the Fisher-scoring method, which is equivalent to fitting the model to the data by iteratively re-weighted least squares.

2) Model selection

We have selected 4 dichotomous factors from 11 factors taking into account the number of parameters and the size of the data set. Even this is the case if there are four dichotomous factors and seven continuous factors, and 10 potential knots for each categorical factor, the total number of unknown parameters involved in the spline logistic model would be 2,937, which are not estimable by the method of maximum likelihood from data sets of sample size 382. In order to reduce the number of parameters contained in the model, we first pre-specified the knot locations. Borderline values of categories were used for the candidates of knots for each categorical factors except for two edges, for an example, candidates of knots for the viewing distance from TV were $r_{11}=1.5$, $r_{12}=2.0$. Even with this in place, the number of parameters involved in the model was still large and we next introduced a model selection procedure that consisted of the following four steps. It enabled us not only to estimate parameters, but also to reduce computational time substantially. Furthermore, the simplicity of the model helped us to interpret the results.

Step1. Consider the main effect model

$$\alpha(X^*) = \beta_0 + \sum_{l=1}^{L} \beta_l X_l + \sum_{l=1}^{L_1}\sum_{m=1}^{M_l} \beta_{lm}(X_l - r_{lm})_+$$

and apply the model selection method described below for selecting the effective knots from $\{r_{11}, r_{12}, \ldots, r_{1M_1}, \ldots, r_{L_1 1}, r_{L_1 2}, \ldots, r_{L_1 M_{L_1}}\}$.

Step2. Considering the following model with the selected knots, apply the model selection method to $X_{l_1} \times X_{l_2}$.

$$\begin{aligned}\alpha(X^*) = \beta_0 &+ \sum_{l=1}^{L} \beta_l X_l + \sum_{l=1}^{L_1}\sum_{m=1}^{M_l} \beta_{lm}(X_l - r_{lm})_+ \\ &+ \sum_{l_1=1}^{L-1}\sum_{l_2=l_1+1}^{L} \beta_{l_1 l_2} X_{l_1} X_{l_2}\end{aligned}$$

Step3. Considering the following model with the selected knots and $X_{l_1}X_{l_2}$, apply the model selection method to $X_{l_1}(X_{l_2} - r_{l_2 m})_+$.

$$\begin{aligned}\alpha(X^*) = \beta_0 &+ \sum_{l=1}^{L} \beta_l X_l + \sum_{l=1}^{L_1}\sum_{m=1}^{M_l} \beta_{lm}(X_l - r_{lm})_+ \\ &+ \sum_{l_1=1}^{L-1}\sum_{l_2=l_1+1}^{L} \beta_{l_1 l_2} X_{l_1} X_{l_2} \\ &+ \sum_{l_1=1}^{L}\sum_{l_2 \neq l_1}^{L_1}\sum_{m=1}^{M_{l_2}} \beta_{l_1 l_2 m} X_{l_1}(X_{l_2} - r_{l_2 m})_+\end{aligned}$$

Step4. Finally consider the following model with the selected knots, $X_{l_1}X_{l_2}$, and $X_{l_1}(X_{l_2} - r_{l_2 m})_+$, and apply the model selection method to $(X_{l_1}-r_{l_1m_1})_+(X_{l_2}-r_{l_2m_2})_+$.

$$\alpha(X^*)=\beta_0+\sum_{l=1}^{L}\beta_l X_l+\sum_{l=1}^{L_1}\sum_{m=1}^{M_l}\beta_{lm}(X_l-r_{lm})_+ +\sum_{l_1=1}^{L-1}\sum_{l_2=l_1+1}^{L}\beta_{l_1l_2}X_{l_1}X_{l_2} +\sum_{l_1=1}^{L}\sum_{l_2\neq l_1}^{L_1}\sum_{m=1}^{M_{l_2}}\beta_{l_1l_2m}X_{l_1}(X_{l_2}-r_{l_2m})_+ +\sum_{l_1=1}^{L_1-1}\sum_{l_2=l_1+1}^{L_1}\sum_{m_1=1}^{M_{l_1}}\sum_{m_2=1}^{M_{l_2}}\beta_{l_1l_2m_1m_2}(X_{l_1}-r_{l_1m_1})_+\times(X_{l_2}-r_{l_2m_2})_+$$

The model selection procedure described in Steps 1–4 is further explained as follows. A hybrid of stepwise addition and deletion procedure is used for selecting the terms in each step. The method starts with the stepwise addition procedure. A new term having the maximum Rao statistic among the candidates is added to the model. This procedure continues until there are no more candidates to enter. Upon stopping, we then carry out the stepwise deletion procedure by successively removing a term possessing the minimum Wald statistic among the candidates. This continues until we arrive at the minimum model. In each step of the stepwise procedure, we compute the Akaike Information Criterion (AIC) associated with the model. Finally, the best model that has the minimum AIC is selected. This model selection procedure is easy to understand conceptually and it can also be easily implemented in SAS using PROC LOGISTIC with forward and backward selection. For more detail see Kawaguchi et al. (2008).[20)]

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