

[DESCRIPTION]

[Title of Invention]

DIOPTER VALUE PREDICTION SYSTEM, DIOPTER VALUE PREDICTION METHOD, AND PROGRAM

[Technical Field]

[0001] The present invention relates to a diopter value prediction system, a diopter value prediction method, and a program.

[Background Art]

[0002] Myopia incidentally occurs when the eyeball axis of a given person is abnormally long. The position of the retina of the eyeball, having undergone axial stretch, falls out of a "normal" focal plane. As a result, the imaging point of a distant object is located in front of the retina, instead of being located on the retina surface.

The degree of strength of myopia/hyperopia/astigmatism is expressed by a diopter (lens power) value. Diopter is a unit of refractive power of a lens (expressed in D). A minus indication (-D) indicates myopia. A plus indication (+D) indicates hyperopia. Normal vision corresponds to ± 0 .

[0003] Patent literature (1) discloses a method of slowing the progress of myopia or hyperopia of a patient. According to the method disclosed in patent literature (1), an eye care

practitioner selects one or more contact lenses from second set of contact lenses based on one or more ocular parameters of the patient, one or more responses of the patient to the contact lens of first set, or both, to provide an improved clinical benefit to the patient compared to the benefit provided by the first set of contact lenses.

In non-patent literature (1), the findings of a research group were reported in the JAMA Ophthalmology Journal dated April 2, 2015. The group mainly consisted of the members of the College of Optometry, Ohio State University, U.S.A. Regarding the prediction of myopia development, this research group has narrowed down risk factors with high probability, based on the assumption of 13 candidate risk factors. Test results indicate that low hyperopic or high myopic refractive errors, found at the early stages of visual acuity tests, will consistently relate to increased risk of subsequent myopia development found in ophthalmology tests.

[Citation List]

[Patent Literature]

[0004]

[PTL 1] JP 2013-501963 A

[Non Patent Literature]

[0005]

[NPL 1] "Prediction of Juvenile-Onset Myopia," [online],
[retrieval on January 5, 2016], Internet <URL:
<https://www.mededge.jp/a/drge/12101>>

[Summary of Invention]

[Technical Problem]

[0006] The above conventional methods, however, are configured only to measure current diopter values and select optimal glasses to prescription. However, use of these methods cannot quantitatively predict future changes in diopter values.

[0007] It is, therefore, one objective of the present invention to provide a diopter value prediction system, a diopter value prediction method, and a program that is able to quantitatively predict future diopter values.

[Solution to Problem]

[0008] In order to solve the above problem, a diopter value prediction system, according to the present invention, comprises input means for inputting a current diopter value (Db) and an age (Age); and calculation means for predicting a diopter value (Da) after elapse of a time interval, based on the diopter value (Db) and the age (Age) input.

Further constituents of the present invention will be described in "Description of Embodiments."

[Advantageous Effects of Invention]

[0009] The present invention provides a diopter value prediction system, a diopter value prediction method, and a program that can quantitatively predict future diopter values.

[Brief Description of Drawings]

[0010]

[Fig. 1] Fig. 1 is a block diagram showing the arrangement of a diopter value prediction system, according to one embodiment of the present invention.

[Fig. 2] Fig. 2 is a graph showing the distribution of Data obtained by the diopter value prediction system according to an embodiment of the present invention (and the corresponding regression curve).

[Fig. 3] Fig. 3 is a graph showing the distribution of Data obtained by the diopter value prediction system according to an embodiment of the present invention (and the corresponding regression curve).

[Fig. 4] Fig. 4 is a flowchart showing the process by which an embodiment of the present invention obtains diopter value predictions.

[Description of Embodiments]

[0011] An embodiment of the present invention is described in detail below with reference to the drawings.

(Embodiment)

Fig. 1 is a block diagram showing the arrangement of a diopter value prediction system according to one embodiment of the present invention.

A diopter value prediction system and method according to this embodiment are used to predict future diopter values.

[0012] As shown in Fig. (1), a diopter value prediction system (1) includes an input means (2), a calculation means (3), a storage means (4), and an output means (5). The input means (2), the calculation means (3), the storage means (4), and the output means (5) are implemented by, for example, a computer including hardware. The input means (2) may be, for example: an input interface, and includes user operations on a pointing device, etc.; and harvesting of Data from external storage media, communication lines, and networks. The output means (5) is, for example: an output interface, including a display unit such as a computer monitor, a printer, writing to external storage media, and outputting to communication lines.

[0013] The calculation means (3) is constituted by, for example: a central processing unit (CPU); and a dedicated circuit. The storage means (4) is constituted by storage media, for example: a random access memory (RAM); a read only memory

(ROM); a hard disk drive (HDD); and a flash[®] memory. The calculation means (3) is realized through program execution processing by the CPU of a computer, including its control unit. A storage unit, included in the computer, stores programs (including a diopter value prediction program) for realizing the functions of the computer, based on commands from the CPU. This realizes cooperation between software and hardware.

[0014] The input means (2) has four inputs: Db (current diopter value), Age (age), Sex (sex), and RL (right/left eyeball).

The calculation means (3) predicts a diopter value (Da) after elapse of interval (time) on the basis of current diopter value (Db) and age (Age). Specifically, the calculation means (3) predicts (Da) for each interval according to a prediction formula for future diopter values using (Db) and (Age) as variables (Math. (4): polynomial in Age in claim 2) or Math. (5) (to be described later). More specifically, the calculation means (3) predicts Da for each interval according to the above polynomial in Age using Db, Age, Sex (sex), RL (right/left eyeball) as variables.

The storage means (4) stores: a prediction formula for future diopter values (Math. (4) or Math. (5)); and table values (see, for example, [Table 4: to be described later] for the

prediction formula (Math. (4) or Math. (5)).

The output means (5), outputs: the diopter values predicted by the prediction formula for future diopter values (Math. (4) or Math. (5)); and further outputs diopter values for recommended glasses or contact lenses, based on the predicted diopter values.

[0015] The diopter value prediction system (1) is described in detail below.

Consider prediction of changes in diopter value after five years. Five-year interval Data was prepared. The five-year interval Data includes 595,389 entries (the records of 116,549 individuals). One entry is represented by Math. (1) given below.

[0016] ID, RL, Sex, Age, Db, Da (1)

where

ID: identification symbol for individual

RL: 1/2 corresponding to right/left

Sex: 1/2 corresponding to male/female

Age: current age

Db: current diopter value

Da: diopter value after elapse of predetermined period (five years)

[0017] The present inventors have focused on the fact that

the introduction of a *spline* function, with respect to age (a smooth interpolation function at joints), leads to significant improvement in accuracy. In addition, the introduction of a spline function with respect to (Db) also leads to significant improvement in accuracy.

[0018] Figs. 2 and 3 show plots of the *spline* function.

Fig. 2 is a graph showing the distribution of Data (and the corresponding regression curve). The horizontal axis represents "current age" (Age), and the vertical axis represents "diopter value after five years - current diopter value" ((Da) - (Db)).

Fig. 2 shows that myopia rapidly progresses in youth, whereas hyperopia gradually progresses at advanced ages.

[0019] Fig. 3 is a graph showing the distribution of Data (and the corresponding regression curve). The horizontal axis represents "current diopter value" (Db), and the vertical axis represents "diopter value after five years" (Da) (a constant is added to Da in Fig. 3 for the sake of convenience).

Fig. 3 shows the linearity of the curve - an almost constant slope, indicating that changes do not depend on "current diopter value." *Ergo*, the changes are steady in terms of time series.

[0020] Prediction is described below. A two-dimensional

spline is considered as a preferable prediction model. In consideration of calculation costs, however, a more practical model is a one-dimensional *spline*, which provides a predictive value given by Math. (2).

$$\begin{aligned} \text{[0021]} \quad D_a = & -0.4112653 + 0.9871306 D_b + s(\text{Age}) + 0.0288855 \\ & \text{Sex} + 0.0032082 \text{ RL} \end{aligned} \quad (2)$$

where $s(\text{Age})$: *spline* function in age.

[0022] A coefficient of D_b is approximately 1. This model is non-linear with respect to age, and can lead to an improvement of 10.8% in terms of mean square error, when compared to a linear model. In comparison with the assumption that diopter values remain constant for five years, this model achieves a reduction in prediction errors of 42.5%. The confidence interval of this prediction has a range of about 2 in diopter value.

[0023] [Diopter Value Prediction after Given Years]

Prediction of diopter values after a given number of years is described below. The source data set includes 125,679 entries with a time interval longer than five years. Due to the diopter values of some persons being measured at a plurality of time points, data at shorter time intervals can be estimated from the five-year interval data.

[0024] Data was prepared in the same manner as in the case

of Math. (1). One entry is given by Math. (3) below:

$$ID, RL, Sex, Age-1, \dots, Age-n, D1, \dots, Dn \quad (3)$$

where

Age-n: n-year old age; and

Dn: diopter value in n-year old age.

[0025] In Math. (3), one entry has n diopter values, and hence $n(n - 1)/2$ year intervals. The number of one-year intervals is very large. The number of overall data points is 3,930,164.

[0026] [Table 1] shows counts in the respective one-year intervals.

[0027]

[Table 1]

interval	0	1	2	3	4	5	6	7	8	9	10
count	35367	26344	95152	13194	85118	82366	44066	45292	61572	6807	4886

[0028] Zero-year interval data, i.e., a plurality of diopter values of the same age, are excluded from the overall data. That is, the number of year-interval data points in use is $3,930,164 - 35,367 = 3,894,797$.

Using the data indicated by Math. (3) and [Table 1], models can be created to predict diopter values after 1 to 10 years.

[0029] These models were used to conduct tests on polynomial regression concerning age represented by Math. (2)

and Math. (4) given below.

$$Da = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Age}^2 + \dots + \beta_i \text{Age}^i + \beta_5 Db + \beta_6 \text{Sex} + \beta_7 \text{RL} \quad (4)$$

where i: integer ranging from 2 to 5.

[Table 2] shows the results obtained by these models.

[0030]

[Table 2]

interval	Db	s	R_by_s	2	3	4	R_by_4	5
1	0.08930	0.08051	0.09843	0.08200	0.08135	0.08105	0.09246	0.08083
2	0.14499	0.11735	0.24036	0.12059	0.11856	0.11790	0.23563	0.11767
3	0.21529	0.15860	0.26331	0.16364	0.16034	0.15938	0.25973	0.15925
4	0.40754	0.21159	0.48081	0.22120	0.21461	0.21268	0.47813	0.21259
5	0.50278	0.28964	0.42392	0.30959	0.29530	0.29175	0.41972	0.29163
6	0.59421	0.31831	0.46432	0.33660	0.32510	0.32080	0.46012	0.31906
7	0.65789	0.33723	0.48740	0.35367	0.34036	0.33804	0.48639	0.33790
8	0.77591	0.40230	0.48151	0.42143	0.40706	0.40350	0.47996	0.40307
9	0.86388	0.44090	0.48963	0.45913	0.44695	0.44381	0.48626	0.44298
10	0.93886	0.47646	0.49251	0.49598	0.48446	0.48228	0.48632	0.48253

where:

interval: year interval between two diopter value measurements;

Db: estimated value of root mean square error (RMSE) when Db (earlier diopter value) is predictive quantity of Da (later diopter value), (hereafter referred to as E_b);

s: estimated value of RMSE of predictive quantity of Da using s (*spline* function) for age (hereafter referred to as E_s);

R_by_s: (E_b - E_s)/E_b (corresponding to error

reduction rate obtained by using spline function of age);

2: estimated value of RMSE of predictive quantity of Da obtained by using *quadratic* function of age;

3: estimated value of RMSE of predictive quantity of Da obtained by using cubic function of age;

4: estimated value of RMSE of predictive quantity of Da obtained by using *quartic* function of age (hereafter referred to as E_4);

R_by_4: $(E_b - E_4)/E_b$ (corresponding to error reduction rate obtained by using *quartic* function of age),

5: estimated value of RMSE of predictive quantity of Da, obtained by using *quintic* function of age.

[0031] Referring to the results in [Table 2], R_by_s, i.e., the error reduction rate, of prediction based on *spline* regression reaches 40% to 50% in the interval ≥ 4 years.

In addition, polynomial regression is slightly worse than *spline* regression in terms of prediction. However, the difference between them is small. In fact, the error reduction rate "R_by_4" based on *quartic* polynomial regression is almost equal to the error reduction rate "R_by_s", based on *spline* regression. The difference between them is generally less than 1%.

A comparison between (2), (3), (4) and (5), as the estimated

values of errors of polynomial regression, shows that the estimated values in (5) are generally smallest. However, the estimated value in (4) in the 10-year interval is smallest. In addition, because differences in model simplicity and error reduction between (4) and (5) are smaller than those between (2) to (4), the present inventors have concluded that (4) is preferable.

[0032] In general, higher-order polynomials lead to smaller errors. Accordingly, it seems preferable to select a higher-order polynomial. However, for the following reason, a *quartic* polynomial is preferred for actual application. First, a quartic polynomial can be calculated by a simple calculator. Second, *quartic* polynomial regression reduces errors to a satisfactory level.

Values shown in [Table 3] indicate a 95% confidence interval of prediction by a *quartic* polynomial.

[0033]

[Table 3]

interval	1	2	3	4	5	6	7	8	9	10
$\pm$	0.569	0.687	0.798	0.922	1.080	1.133	1.163	1.270	1.332	1.389

[0034] [Prediction Formula for Future Diopter Values]

A prediction formula (polynomial in age) for future diopter values is represented by general Math. (5) given below.

Note however, that Table 4 provides coefficients. Prediction Math. (5) for diopter values is a *quartic* function of age, disclosed for the first time by the present inventors.

$$[0035] \quad Da = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Age}^2 + \beta_3 \text{Age}^3 + \beta_4 \text{Age}^4 + \beta_5 Db + \beta_6 \text{Sex} + \beta_7 \text{RL} \quad (5)$$

where:

Da: diopter value after elapse of predetermined period,

β_n : coefficient taking value in table represented by respective ages and respective terms of polynomial,

Age: current age,

Db: current diopter value

Sex: 1/2 corresponding to male/female, and

RL: 1/2 corresponding to right/left

[0036]

[Table 4]

interval	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7
1	-0.1039	45.31	-30.39	25.55	-16.86	0.9923	0.006172	0.0005589
2	-0.1708	70.47	-44.20	34.86	-21.27	0.9915	0.01307	0.001559
3	-0.2472	92.72	-54.93	41.71	-24.78	0.9897	0.02352	0.001904
4	-0.3310	125.2	-74.74	57.00	-33.65	0.9881	0.03028	0.002851
5	-0.4168	215.4	-130.9	98.12	-56.85	0.9855	0.02969	0.003241
6	-0.5144	168.7	-99.11	67.70	-31.18	0.9820	0.03705	0.003673
7	-0.5740	149.1	-83.24	53.88	-23.32	0.9809	0.04835	0.004822
8	-0.6308	131.0	-70.12	46.84	-21.30	0.9777	0.04836	0.005165
9	-0.7104	108.4	-56.59	38.47	-18.37	0.9745	0.06114	0.005588
10	-0.7559	74.36	-39.26	25.04	-12.10	0.9753	0.07797	0.002963

[0037] The operation of diopter value prediction system (1), having the above arrangement, is described below.

Fig. 4 is a flowchart showing diopter value prediction, by the diopter value prediction system (1). For example, a CPU, as a part of the calculation means (3), executes this procedure.

First, in step S1, the input means (2), inputs Db (current diopter value), Age (age), Sex (sex), and RL (right/left eyeball). The input means (2) includes, for example: user operations on a pointing device, etc.; and harvesting of Db (current diopter value) and Age (age) data from external storage media or a communication line.

Next, in step S2, the calculation means (3) reads out the prediction formula for future diopter values (Math. (5)) and table values ([Table 4]) stored in the storage means (4).

[0038] Next, in step S3, the calculation means (3) predicts the diopter value (Da) for each interval, after elapse of interval, according to the polynomial in Age (Math. (5)), using Db, Age, Sex (sex), and RL (right/left eyeball) as variables.

Next, in step S4, the output means (5) outputs the predicted diopter values and further outputs diopter values for recommended glasses, based on the predicted diopter values. The output means (5) outputs the predicted diopter values and the diopter values for the recommended glasses to, for example, a display unit and a printer. The output means (5) includes

writing to an external storage medium and outputting to a communication line such as a network.

[0039] As described above, the diopter value prediction system (1), according to this embodiment, comprises: the input means (2) for inputting Db (current diopter value), Age (age), Sex (sex), and RL (right/left eyeball); the calculation means (3) for predicting the diopter value Da after elapse of interval (time) on the basis of Db (current diopter value) and Age (age); the storage means (4) for storing the prediction formula for future diopter values (Math. (5)) and the table values ([Table 4]); and the output means (5) for outputting the predicted diopter values, as well as further outputting the diopter values for the recommended glasses, based upon the predicted diopter values.

In this embodiment, the calculation means (3) predicts Da for each interval, according to the prediction formula for future diopter values (Math. (5)), and the table values ([Table 4]) using Db, Age, Sex (sex), and RL (right/left eyeball) as variables.

[0040] A diopter value prediction method, used in the diopter value prediction system (1), causes the computer to execute: an input step of inputting the current diopter value (Db) and the age (Age); a calculation step of reading out the

prediction formula for future diopter values (Math. (4) or (5)), and table values (for example, [Table 4]) from the storage means (3); and a prediction of (Da) for each interval, according to the prediction formula for future diopter values (Math. (4) or (5)). The table values (for example, [Table 4]). Db, Age, Sex (sex), and RL (right/left eyeball) are used as variables. Calculations are based upon input Db and Age. Finally, the computer executes an output step - outputting the predicted diopter values, and further outputting diopter values for recommended glasses, based upon the predicted diopter values.

[0041] This process makes it possible to predict future diopter values (for example, after five years). It is further possible to output diopter values for glasses to prescribe, in accordance with the prediction. Predicting future diopter values makes it possible to estimate risks such as future myopia, and manage such risk, in advance.

[0042] The present invention is not limited to the above embodiment and includes other modifications and applications within the spirit of the present invention, described in the scope of the appended claims.

[0043] In addition, the diopter value prediction system and the diopter value prediction method, each may include a calculation function, implemented by independent hardware or

software in the diopter value prediction system. Furthermore, the diopter value prediction system, the diopter value prediction method, program calculation, and arithmetic processing, may be implemented by application specific integrated circuits (ASICs), etc., instead of computer programs.

[0044] Furthermore, information such as: programs; tables; and files for realizing the respective functions, can be held in a storage device. Such storage devices may include: hard disk, or solid state drive (SSD); or a storage medium such as an integrated circuit (IC) card, secure digital (SD) card, or optical disk. Furthermore, in this description, the processing step of writing time-series processing, is not limited to processing to be performed in a time-series manner, in accordance with a written order. It also includes processing to be concurrently or individually executed (for example, parallel processing or object-oriented processing). This need not always be processed in a time-series manner.

In addition, the above embodiment uses the title "diopter value prediction system and diopter value prediction method." However, this title has been adopted for the sake of convenience. It is possible to adopt, for example, titles such as "diopter value prediction apparatus" or "diopter value calculation

method.”

[0045] The disclosure of Japanese Patent Application No. 2016-128315, filed on June 29, 2016, including the description, claims, and drawings is incorporated herein, by reference to its entirety.

All the publications, patents, and patent applications cited in this description are incorporated in their entirety, by reference herein.

[Reference Signs List]

[0046]

1 diopter value prediction system

2 input means

3 calculation means

4 storage means

5 output means

[CLAIMS]

[Claim 1] A diopter value prediction system comprising:

input means for inputting a current diopter value (Db) and an age (Age);

calculation means for predicting a diopter value (Da) after elapse of a time interval, based on the diopter value (Db) and the age (Age) input by the input means; and

output means for outputting the diopter value (Da) calculated by the calculation means.

[Claim 2] The diopter value prediction system according to claim 1, wherein the calculation means predicts the diopter value (Da) for each interval according to a polynomial in Age - using the diopter value (Db) and the age (Age) as variables.

[Claim 3] The diopter value prediction system according to claim 2, wherein the calculation means predicts the diopter value (Da) for each interval according to the polynomial in Age - using the diopter value (Db), the age (Age), a sex (Sex), and right/left eyeball (RL) as variables.

[Claim 4] The diopter value prediction system according to claim 2, comprising:

storage means for storing the polynomial in Age, and a table value for the polynomial in Age.

[Claim 5] The diopter value prediction system according to

claim 2, wherein the output means outputs a diopter value for recommended glasses - based on a diopter value predicted by the polynomial in Age.

[Claim 6] The diopter value prediction system according to claim 2, wherein the polynomial in Age is a *quartic* function of the age (Age).

[Claim 7] The diopter value prediction system according to claim 2, wherein the polynomial in Age is represented by a formula given below

$$Da = \beta_0 + \beta_1 \text{Age} + \beta_2 \text{Age}^2 + \beta_3 \text{Age}^3 + \beta_4 \text{Age}^4 + \beta_5 Db + \beta_6 \text{Sex} + \beta_7 \text{RL}$$

where:

Da: diopter value after elapse of predetermined period,

β_n : coefficient of each term of polynomial,

Age: current age,

Db: current diopter value

Sex: 1/2 corresponding to male/female, and

RL: 1/2 corresponding to right/left

[Claim 8] A diopter value prediction method comprising:

an input step of inputting a current diopter value (Db) and an age (Age);

a calculation step of predicting a diopter value (Da) after elapse of a time interval based on the diopter value (Db)

and the age (Age) input in the input step; and

an output step of outputting the diopter value (Da) calculated in the calculation step.

[Claim 9] A program for causing a computer to function as

a diopter value prediction system comprising: input means for inputting a current diopter value (Db) and an age (Age); calculation means for predicting a diopter value (Da) after elapse of a time interval - based on the diopter value (Db) and the age (Age) input by the input means; and output means for outputting the diopter value (Da) calculated by the calculation means.