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Detecting early symptoms of mental health deterioration using handwriting duration parameters

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Abstract

Introduction: Recent years have witnessed a rapid rise in the incidence of mental health deterioration, such as depression and depressive symptoms. Therefore, early detection and measures of prevention have become important. This study aimed to develop a predictive method for assessing the incident risk of mental health deterioration by examining the associations between mental health and handwriting duration.

Methods: A cohort study over four years was performed with 200 university students who volunteered to participate in this study. Participants received the Uchida-Kraepelin test every April and completed the 30-item general health questionnaire to evaluate their mental health. From the stroke data obtained from the digital pen in the Uchida-Kraepelin test, two kinds of intervals were extracted. Based on these interval ratios, participants were divided into two groups. We then examined the scores of the questionnaire between the high-risk group and the low-risk group in the first year of the study. In addition, multiple logistic regression analysis was used to examine whether those in the high-risk group in the first year still belonged to the high-risk group in the fourth year.

Results: In the "Anxiety and Dysphoria scale" in the first year, the high-risk group had a significantly higher score than the low-risk group. Additionally, it was found that those in the high-risk group in the first year tended to still be in the high-risk group in the fourth year.

Conclusion: These results suggested that the indicator that we developed can be used as a predictive factor for the incident risk of mental health deterioration.

KEYWORDS

cohort study, handwriting duration, mental health, Uchida-Kraepelin test, university students

1 | INTRODUCTION

Worldwide, an increasing number of people are believed to be suffering from mental health deterioration stemming from psychiatric disorders, such as depression and depressive symptoms. This deterioration can substantially affect their quality of life, including the ability to work, with more people electing to take long-term sick leaves.[1-3] Mental health deterioration is characterized by a wide range of disturbances, either psychological or behavioral, which can affect both the mental and the physical health of workers. It includes various psychiatric disorders, along with abnormal levels of worry and anxiety, and is classified under the label of psychological and behavioral disorders.[4] According to a 2014 survey that was conducted by the Ministry of Health, Labour and Welfare on patients, a total of 3.924 million people are living with psychiatric disorders in Japan. Moreover, the number of patients with mood disorders (eg, depression and bipolar disorder) in Japan reached 1.116 million, passing 1 million for the first time since the start of the survey. The recurrence rate of mental health deterioration, particularly that of depression, is considered to be high,[5] with a 50% probability that a patient that developed depression for the first time will exhibit recurrence. Furthermore, that of a third or fourth recurrence is 75% and greater than 90%, respectively. In these cases, the patients have to take repeated sick leaves or quit their jobs. Therefore, a measure for early detection to prevent the onset of depression and its recurrence is considered necessary.

As a simplified method to measure depressive symptoms, a self-administered questionnaire is often used. In the major depressive disorder (MDD) screening using the Beck Depression Inventory (BDI)[6] developed by Beck, a cutoff score of ≥4 was demonstrated to reveal the presence or absence of MDD symptoms.[7-9] Likewise, the 30-item general health questionnaire (GHQ30), which can measure mental well-being at the time of the survey, is used for MDD screening and other depression symptom assessments.[10-13] However, since the questionnaire has a subjective test form, an objective index is needed.

Accordingly, the aim of the present study was to develop a predictive method for assessing the incident risk of mental health deterioration and evaluate its predictive accuracy by examining the association between mental health and handwriting duration.

As a preliminary examination, we conducted a cross-sectional study targeted at participants of a return to work program.[14] The participants of this program were individuals who took leave time from work for mental health disorders, who have been diagnosed as being in remission since the symptoms of their mental health disorders had stabilized with treatment, such as with medications, and who aim to return to work. When a digital pen-based Uchida-Kraepelin test referred to in the next Methods section was administered to the 26 participants (hereinafter referred to as the on leave group) and 20 healthy individuals (hereinafter referred to as the normal group), the stroke interval ratio t_2/t_1 values defined in the same Methods section were 7.2 ± 3.3 in the on leave group and 4.4 ± 0.79 in the normal group, which were significantly different between the two groups ($P < .001$). Conversely, when the 4 measurements that can be acquired with a digital pen, coordinates (x, y), time, and pencil pressure were used, writing speed, acceleration of writing speed, stroke distance, and two types of stroke interval time can be acquired. For these parameters, only t_2/t_1 values were found to be significantly different between the on leave and normal groups. From the results of these preliminary examinations, it could be inferred that the stroke interval ratio t_2/t_1 value is one of the influential indicators of mental health deterioration, and the higher t_2/t_1 value, the higher the risk of mental health deterioration.

Based on this preliminary study, in this study, in order to develop a method for predicting the incidence risk of mental health using handwriting duration, a cohort study (follow-up study) was performed.

2 | METHODS

2.1 | Study design

In this study, in order to develop a method for predicting the incidence risk of mental health using handwriting duration, a cohort study (follow-up study) was performed. The variables used in this study were obtained from the Uchida-Kraepelin test, and a digital pen was used in the questionnaire.

2.2 | Participants

Out of 256 students in their first year at Toyo University in 2010, 200 students (127 males, 73 female, age: 18–22), from whom voluntary consent was obtained, participated in this four-year cohort study. Ultimately, 151 participants (95 males, 56 females) completed the entire four-year-long survey.

2.3 | Survey method

The participants took the Uchida-Kraepelin test, in which a digital pen is used, and self-administered the GHQ30, which measures the level of mental health, every April over four years from 2010 to 2013. The GHQ30 was distributed to the participants at the time of the survey, and completion was checked upon reception.

2.4 | *Digital pen*[15]

In this study, the Anoto DP-201 digital pen was used, which can record handwriting information at a spatiotemporal resolution of 13 ms and 0.3 mm. At the tip of the digital pen, there is a charge-coupled device camera that recognizes 6 × 6 dot patterns on digital pen–compatible sheets and identifies the position on the paper with an information processor. Since these dots are lined up in either the

top, down, left, or right direction from the virtual grid, with a diameter of 0.3 mm, the digital pen can recognize unique dot patterns on the paper. Using this digital pen, the participants were asked to fill in the digital pen–compatible form in ink just as they do with a normal ballpoint pen. During the handwriting session, the location information (x, y) of the pen tip and information on the time and pen pressure were obtained and temporarily saved in the memory. The stored handwriting data was then transferred to a PC via USB/Bluetooth.

2.5 | Uchida-Kraepelin test

The Uchida-Kraepelin test is a stress load test that requires participants to perform a single-digit addition as fast as they can. The test sheet used is a paper on which 115 single-digit numbers are printed across 34 rows.[16] The participants were asked to view these horizontally aligned numbers according to the instruction of the test CD and, from the first row, add the first and second numbers together, followed by the second and third number, and so on. The participants then wrote an answer in the blank between the two numbers. If the answer was 10 or greater, they were asked to write the number in the unit place; for example, if the answer is 12, they were asked to write the units digit "2." The participants changed the line every minute and carried on calculating for 15 minutes (15 rows). After a 5 minutes break, they took the test for another 15 minutes (15 rows). The test results are generally assessed using the added-work curve drawn on the paper. However, the added-work curve was not used in this study.

2.6 | Mental health questionnaire

In order to measure the mental health of the participants, GHQ30 was used in this study, which is composed of six scales (general illnesses, somatic symptoms, sleep disturbances, social dysfunction, anxiety and dysphoria, and suicidal depression) with five questions each.[17] In this system, the higher the score, the lower the level of mental health (score range: 0-30). GHQ30 was chosen because it is a general mental health questionnaire that covers a wide range of adult ages. Because this study targeted persons unaffected by mental illness, we concluded that a disease-screening questionnaire, such as the K10, would not be suitable.

2.7 | Risk indicator for mental health deterioration

From the handwriting data recorded using the digital pen, if the stroke interval (at the time when not writing) corresponding to one stroke is displayed in terms of logarithmic time (log s), two peaks are obtained as shown in Figure 1. The peak on the left side indicates the interval between the first and second strokes of the numbers 4, 5, and 7 and is termed the "interval time within numbers". Almost all Japanese people write the numbers 4, 5, and 7 with two strokes. For the number 4, the first stroke is a diagonal and horizontal line, whereas the second stroke is a long vertical line. For the number 5, the first stroke is a vertical and semi-circular line, whereas the second stroke is a horizontal line. For the number 7, the first stroke is a short vertical line, whereas the second stroke is a horizontal and long diagonal line. On the other hand, the peak on the right side indicates the interval after finishing writing a number and before starting to write the next number and is termed the "the interval time between numbers." The mean logarithmic time of these two-stroke intervals is expressed as t_1 and t_2, respectively, and the ratio of the two (t_2/t_1) is regarded as the "stroke interval ratio." In this study, the t_2/t_1 value was defined as the risk indicator of mental health deterioration.

2.8 | Thresholds for mental health deterioration risk

In this study, a clustering method was used to divide the participants into a high-risk group and a low-risk group for mental health deterioration, and the threshold between the two groups was calculated. The clustering method is a classification method that is used when there are two or more data items that need to be classified into several groups (clusters) according to their similarity and

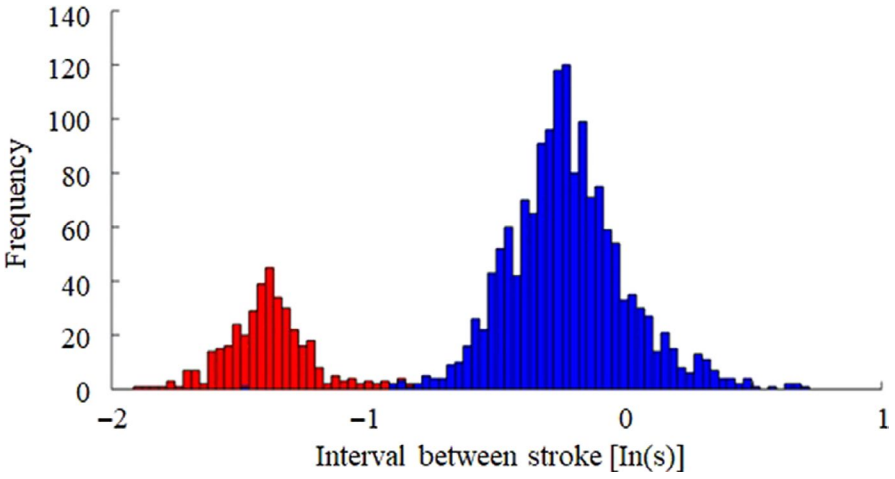

FIGURE 1 Distribution of the stroke intervals from the handwriting data recorded using the digital pen. (The left side peak shown in red.) The interval between the first and second strokes of the numbers 4, 5, and 7 (numbers written by two strokes, in general) (the right side peak shown in blue). The interval after finishing writing a number and before starting to write the next number

distance (dissimilarity).[18] In this study, four-dimensional data were created using the t_2/t_1 values over four years and the participants were divided into two groups (Group A: participants with larger t_2/t_1 values; Group B: participants with lower t_2/t_1 values) using the hierarchical clustering group average method. In addition, in order to obtain the t_2/t_1 threshold between Group A and Group B, the four-dimensional vector coordinates that separated the two groups were calculated and the mean of these coordinates was regarded as the risk threshold for mental health deterioration. Based on this threshold, the high-risk group was defined as those at the threshold or above, whereas the low-risk group was defined as those below the threshold. As a clustering method, MATLAB R2018b Statistics and Machine Learning Toolbox were used.

2.9 | Statistical analysis

The appropriate statistical methods were determined after assessing the normality of each variable using the Shapiro-Wilk test. The Mann-Whitney U test was used for continuous variables and the chi-squared test was used for categorical variables (Fisher's direct method if the expected frequency was below 5) to compare the two groups. For items in which a significant difference was noted, a residual analysis was performed to check which category was significant and items with high significance (or low significance) were identified. Moreover, changes over time were analyzed using the multiple logistic regression analysis. For all statistical analyses, SPSS (v.24) for Windows was used and all the tests were two-sided (except for Fisher's direct method, which is one-sided) and the statistical significance level was below 5%.

In this study, the characteristics of the participants in the high-risk group and the low-risk group in the first year and the handwriting duration values (t_1 and t_2) were first examined. Afterward, the score of each scale of the GHQ30 between the high-risk group and the low-risk group in the first year was examined. Lastly, in order to examine whether those in the high-risk group in the first year still belonged to the high-risk group in the fourth year, multiple logistic regression analysis was used to examine the associations between the high-risk group and the low-risk group in the first year and in the fourth year.

TABLE 1 Differences in the participants' and handwriting characteristics and GHQ30 scores at 1 year between the low-risk and high-risk groups

	Low-risk group[a] (n = 141)	High-risk group[b] (n = 10)	*P*-value
Participants' characteristics			
Age[c]			
Year	18.17 ± 0.55	18.00 ± 0.00	.195
Sex (%)[d]			
Male	93 (66.0)[e]	2 (20.0)[f]	.006
Female	48 (34.0)[f]	8 (80.0)[a]	
Handwriting characteristics			
t_2/t_1 ratio[c]	6.00 ± 1.62	12.14 ± 2.27	.000
t_1 ratio[c]	0.13 ± 0.04	0.10 ± 0.02	.013
t_2 ratio[c]	0.76 ± 0.23	1.26 ± 0.33	.000
GHQ30			
Total score[c]	5.60 ± 4.55	8.20 ± 4.52	.065
General illnesses[c]	0.94 ± 0.92	1.30 ± 1.06	.273
Somatic symptoms[c]	0.96 ± 1.10	1.30 ± 1.25	.332
Sleep disturbances[c]	1.14 ± 1.21	1.00 ± 0.67	.855
Social dysfunction[c]	0.48 ± 0.85	0.60 ± 0.84	.523
Anxiety and dysphoria[c]	1.50 ± 1.55	2.80 ± 1.81	.024
Suicidal depression[c]	0.59 ± 1.29	1.20 ± 1.75	.196
Risk of mental health disorders			
2nd year[d]			
Low-risk group	136 (96.5)	4 (40.0)	.000
High-risk group	5 (3.5)	6 (60.0)	
3rd year[d]			
Low-risk group	138 (97.9)	2 (20.0)	.000
High-risk group	3 (2.1)	8 (80.0)	
4th year[d]			
Low-risk group	138 (97.9)	4 (40.0)	.000
High-risk group	3 (2.1)	6 (60.0)	

Note: Data are presented as the mean ± standard deviation (SD) or the number of participants (%).

[a]Low-risk group ($t_2/t_1 < 10$).

[b]High-risk group ($t_2/t_1 \geq 10$).

[c]Mann-Whitney U test (two-sided test).

[d]Chi-squared test (two-sided test).

3 | RESULTS

3.1 | Indicators of mental health deterioration risk used in this study

As previously mentioned, the parameters of writing speeding, acceleration of writing speed, stroke distance, and two types of stroke interval time obtained from data acquired with digital pens were correlated with the total GHQ30 score and the values of each scale; however, no significant correlations were found for any parameter.

3.2 | Threshold for mental health deterioration risk

The mean t_2/t_1 values for each year from 2010 to 2013 of the two groups, Group A and Group B, into which the participants were divided through clustering were as follows: Group A (13.24, 11.68, 10.69, and 11.69) and Group B (6.12, 5.79, 5.85, and 5.74). In addition, as a result of calculating the threshold for the t_2/t_1 values between the two groups, the four-dimensional vector coordinates were 11.15, 9.95, 9.27, and 9.94, respectively, with the mean of these

coordinates being 10.08. Based on these results, the threshold for the mental health deterioration risk was determined as $t_2/t_1 = 10$, and the participants were divided into a high-risk group ($t_2/t_1 \geq 10$) and a low-risk group ($t_2/t_1 < 10$) accordingly. In the first year, 10 participants were in the high-risk group and 141 were in the low-risk group.

3.3 | Statistical analysis results

3.3.1 | Participant characteristics and handwriting duration

The characteristics of the participants and the handwriting duration values are shown in the higher section of Table 1. The mean age of the participants in the first year was 18.00 ± 0.00 for the high-risk group and 18.17 ± 0.55 for the low-risk group; this difference was not significant. As for the male-to-female ratio, the high-risk group was found to have a significantly higher female ratio compared with the low-risk group (Table 1; $P < .001$). Moreover, in terms of handwriting duration, the high-risk group had significantly lower t_1 values compared with the low-risk group (Table 1; $P < .05$). Likewise, the high-risk group had significantly higher t_2 values compared with the low-risk group (Table 1; $P < .001$).

3.3.2 | GHQ30

The mean and standard deviation for the GHQ30 total scores and the scores from the individual subscales are shown in the middle row of Table 1. These show that in the first year, the high-risk group was shown to have higher Anxiety and Dysphoria scores compared with the low-risk group (Table 1; $P < .05$). In addition, it was found that the high-risk group tended to have a higher total score in the GHQ30 compared with the low-risk group (Table 1; $P < .10$). No significant differences were observed between the two groups for other variables.

3.4 | Relationship between the first-year distribution to high-risk and low-risk groups and the distribution in the second, third, and fourth years

The lower section of Table 1 lists absolute and percentage values for individuals who, respectively, belonged to the low-risk group and high-risk groups in the first year, indicating which group they subsequently belonged to in the second, third, and fourth years. From the results of a chi-squared test, it was found that individuals in the high-risk group in the first year, compared with those belonging to the low-risk group, were significantly more likely to belong to the high-risk group in the second, third, and fourth years, respectively (Table 1; $P < .001$ each).

TABLE 2 Relationship between the risks of mental health disorders at 1 and 4 years

				95% CI	
	β	*P*	OR	Lower	Upper
Crude					
Risk of mental health disorders in the 1st year	4.23	.000	69.00	12.54	379.81
Model 1					
Risk of mental health disorders in the 1st year	4.35	.000	77.41	12.84	466.88
Age	0.47	.592	1.60	0.29	8.99
Model 2					
Risk of mental health disorders in the 1st year	4.75	.000	115.94	11.60	1,158.46
Sex	−0.91	.434	0.40	0.04	3.96
Model 3					
Risk of mental health disorders in the 1st year	4.84	.000	126.62	12.10	1,325.57
Age	0.41	.630	1.51	0.28	8.14
Sex	−0.89	.446	0.41	0.04	4.08

Note: Crude: chi-squared test, $P < .001$, percentage of correct classifications: 95.36%.

Model 1: risk of mental health disorders in the 1st year, age; chi-squared test, $P < .001$, percentage of correct classifications: 95.36%.

Model 2: risk of mental health disorders in the 1st year, sex; chi-squared test, $P < .001$, percentage of correct classifications: 95.36%.

Model 3: risk of mental health disorders in the 1st year, age, sex; chi-squared test, $P < .001$, percentage of correct classifications: 95.36%.

Abbreviations: CI, confidence interval; OR, odds ratio.

TABLE 3 Descriptive statistics at one year of taking a leave of absence or quitting the school

	Taking a leave or quitting the school (n = 3)		
	1	2	3
Age	18	20	18
Sex	Female	Female	Female
t_2/t_1 ratio	8.77	7.30	14.19
t_1 ratio	0.16	0.17	0.12
t_2 ratio	1.36	1.25	1.77
Total score	11	13	17
General illnesses	1	2	3
Somatic symptoms	0	2	0
Sleep disturbances	4	5	2
Social dysfunction	0	0	4
Anxiety and dysphoria	4	4	5
Suicidal depression	2	0	3

Associations between the high-risk and low-risk groups in the first year and in the fourth year. Table 2 summarizes the results of using multinomial logistic regression analysis to examine the association between the high-risk and low-risk groups in the first year and fourth year, respectively. Compared with those in the low-risk group in the first year, those in the high-risk group in the first year had a significantly higher rate of belonging to the high-risk group in the second, third, and fourth years (Table 1; $P < .001$). Binominal logistic regression analysis (crude) further revealed that those in the high-risk group in the first year were associated with the high-risk group in the fourth year (Table 2; $P < .001$, odds ratio [OR]: 12.54-379.81). Similarly, in each of Model 2 (which considers age), Model 3 (which considers sex), and Model 4 (which considers both age and gender), it was found that the high-risk group in the first year was significantly associated with the high-risk group in the fourth year (for each of Models 2, 3, and 4; $P < .001$, OR: 12.84-466.88; $P < .001$, OR: 11.60-11 158.46; $P < .001$, OR: 12.10–1325.57). These results indicated that those in the high-risk group in the first year were more likely to belong to the high-risk group in the fourth year, as well, even taking into account the effects of age and sex.

3.4.1 | Case of leave of absence from the school or quit the school students

Of the 200 volunteer university students, three students took a leave of absence from the school or quit the school over the 4-year study period. The t_2/t_1 value, the total score of the GHQ30, and the Anxiety and Dysphoria scores were all higher for those who took a leave of absence or quit the school (Table 3). While two of these three students did not belong to the high-risk group in the first-year survey, all three were included in the high-risk group due to the fact that in each case their t_2/t_1 value on the survey conducted in the year before they left school was found to be equal to or greater than 10. These results showed that those who took a leave of absence or quit the school had lower levels of mental health and higher levels of anxiety in the first year and, hence, had a higher risk of mental health deterioration. In contrast, the t_2/t_1 value, the total score of the GHQ30, the Sleep Disturbance score, and the Anxiety and Dysphoria scores were all lower for those who did not take a leave or quit the school in the first year (Table 4).

4 | DISCUSSION

In this study, the threshold for mental health deterioration risk was analyzed using the hierarchical clustering group average method. As a result, the four-dimensional vector correlates were 11.15, 9.95, 9.27, and 9.94 for each year, with a mean of 10.08. The threshold for the mental health deterioration risk was defined as $t_2/t_1 = 10$. It has been suggested in previous studies that, between those with deteriorated mental health and healthy individuals, the former have significantly higher t_2/t_1values.[18,19] The results of this study are in line with the findings of these previous studies.

In this study, there was no significant difference in the age of the participants between the high-risk group and the low-risk group. All participants in this study were university students (18-22 years of age), representing a small age range. In addition, the number of females in the high-risk group was significantly higher compared with the low-risk group. In a 2014 survey by the Ministry of Health, Labour and Welfare, 1.116 million people had dysphoria, of whom 0.70 million were females, representing a larger proportion than males.[1] The American Psychiatric Association reported that the prevalence of depression in females in their early adolescence is 1.5- to 3.0-fold higher compared with their male

TABLE 4 Descriptive statistics at 1 year of not taking a leave or quitting the school

	Not taking a leave or quitting the school (n = 197)				
	Mean	SD	Median	Min.	Max.
Age	18.18	0.52	18	18	22
t_2/t_1 ratio	6.36	2.15	5.93	2.01	16.32
t_1 ratio	0.13	0.04	0.12	0.07	0.46
t_2 ratio	0.81	0.26	0.77	0.42	2.13
Total score	5.77	4.67	5	0	20
General illnesses	0.98	0.97	1	0	4
Somatic symptoms	0.98	1.17	1	0	5
Sleep disturbances	1.13	1.18	1	0	5
Social dysfunction	0.49	0.84	0	0	4
Anxiety and dysphoria	1.57	1.63	1	0	5
Suicidal depression	0.61	1.25	0	0	5

Abbreviation: SD, standard deviation.

counterparts.[5] Our present study results coincide with these previous findings.

In the methods used in this study, we used two kinds of intervals involving calligraphic motion based on handwriting information. The t_1 value is the interval between the first and second strokes of the two-stroke numbers (4, 5, and 7) and was found to be inversely correlated with the writing speed ($r = -.35$, $P < .01$). Therefore, the t_1 value is considered to represent the speed of "writing." Meanwhile, the t_2 value is the interval after finishing writing a number and before starting to write the next number and is considered to represent the speed of calculation (thinking) plus, until executing the handwriting movement, the related cognitive function. Our study results demonstrated that the participants in the high-risk group wrote quicker in terms of handwriting but slower in terms of executing the writing movement after thinking compared with the low-risk group. Patients who suffer from depressive symptoms often report a decline in subjective cognitive speed.[20,21] Moreover, it has been suggested that depressed patients have significantly slower information processing speeds, as measured by the Paced Visual Serial Addition Test (PVSAT), compared with healthy controls.[22] The Uchida-Kraepelin test used in this study is quite similar to the PVSAT method; the t_2 value indicates cognitive function, with larger t_2 values indicating reduced cognitive function. Since t_2 values were found to be positively correlated with t_1 values ($r = .39$, $P < .001$), among healthy individuals, those who calculate quickly can write quickly and those who calculate slowly can write slowly. Thus, when normalizing the t_2/t_1 ratios using the t_1 values, the t_2/t_1 value becomes larger in the high-risk group regardless of the speed of writing, suggesting that it may represent a risk indicator for reduced cognitive function (ie, mental health deterioration).

The results of this study revealed that the high-risk group in the first year had significantly higher scores on the Anxiety and Dysphoria scale compared with the low-risk group. This indicated that the high-risk group had a higher level of anxiety compared to the low-risk group. The Anxiety and Dysphoria scale had a strong, positive correlation with the GHQ30 ($r = .83$, $P < .01$), and there was a difference in the total score of the GHQ30 between the high-risk group and the low-risk group ($P < .10$). Our study findings demonstrated that the t_2/t_1 value used to divide the participants into groups was associated with mental health, particularly with anxiety.

From the results of this study, those in the high-risk group in the first year had a higher rate of belonging to the high-risk group in the second, third, and fourth years compared with those in the low-risk group in the first year. Moreover, the multiple logistic regression analysis demonstrated that the high-risk group in the first year was significantly correlated with the high-risk group in the fourth year, demonstrating that those in the high-risk group in the first year were more likely to belong to the high-risk group in the fourth year. These results showed that the t_2/t_1 value that we used as a way to divide the participants into groups may be a predictive factor for mental health deterioration risk.

Of the 200 volunteer university students, three students took a leave of absence from the school or quit the school over the four-year study period. The t_2/t_1 value, the total score of the GHQ30, and the Anxiety and Dysphoria scores were all higher for those who took a leave of absence or quit the school (Table 3). These results showed that those who took a leave of absence or quit the school had lower levels of mental health and higher levels of anxiety in the first year and, hence, had a higher risk of mental health deterioration. In contrast, the t_2/t_1 value, the total score of the GHQ30, the Sleep Disturbance score, and the Anxiety and Dysphoria scores were all lower for those who did not take a leave or quit the school in the first year (Table 4). Therefore, the t_2/t_1 value that we used as a way to divide the participants into groups can be used as a predictive factor for mental health deterioration risk.

There were several limitations in this study. First, there was a large gap in the number of participants (n-value) who belonged to the high-risk group compared with the low-risk group. When there is a large gap in the n-value, the statistical power tends to be reduced. Thus, there may be variables that were falsely determined as having no statistical difference. Moreover, since only a small number of people belonged to the high-risk group, if we increase the number of participants in a future study, the significant differences found in this study may disappear. Secondly, the volunteers who participated in this study were Japanese university students. Therefore, the same screening procedure may not necessarily be recommended for other groups of people, including the elderly and people in other countries. Finally, we did not examine the association between mental health deterioration risk and stress. The Ministry of Health, Labour and Welfare has required all businesses to implement a stress check program beginning from December 1, 2015.[23] Indeed, by examining the association between the t_2/t_1 value, the risk indicator for mental health deterioration that we have proposed in the current study, and the stress check, we believe that a feasible screening method for mental health deterioration could be developed.

The findings of this study suggest that the t_2/t_1 value, involving two types of handwriting durations, represents a promising risk indicator for mental health deterioration.

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CONFLICT OF INTEREST

None.

AUTHOR CONTRIBUTIONS

Mashio Y conducted data curation, statistical analysis, and writing of the manuscript. Kawaguchi H conducted designing of this study, writing of the manuscript, and research management.

DATA REPOSITORY

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy and ethical restrictions (ie, we did not obtain informed consent on the public availability of raw data).

APPROVAL OF THE RESEARCH PROTOCOL BY AN INSTITUTIONAL REVIEWER BOARD

This study was approved by the Ethics Committee of Toyo University (No. 2009-S-1).

INFORMED CONSENT

Informed consent was obtained from all participants.

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