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Research Article

A New Objective Health Numeracy Test for Patients with Type 2 Diabetes: Development and Evaluation of Psychometric Properties

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ABSTRACT

Purpose: Patients with diabetes frequently need to perform certain numeric tasks such as interpreting blood glucose levels. However, there is no psychometrically sound instrument for objectively measuring diabetes-specific health numeracy. This study aimed to develop a new objective diabetes health numeracy test (DHNT) and evaluate its psychometric properties in adult patients with type 2 diabetes.
Methods: An instrument development study was conducted. Initial items were evaluated by six experts for content validity. After a pilot test, a convenience sample of 257 participants with type 2 diabetes was recruited at 2 university hospitals from May to September 2018. The structural, convergent, and criteria validity, and internal consistency of the DHNT with binary item responses were evaluated. Data were analyzed using exploratory factor analysis, Rasch analysis, tetrachoric correlation, Spearman's correlation, and the Kuder–Richardson-20 formula.
Results: Exploratory factor analysis yielded a single-factor solution comprising seven items. Rasch analysis confirmed that no item did not fit with the single factor and identified that the item difficulty parameters had moderate values. The convergent and criterion validity of the instrument were demonstrated, with diabetes knowledge and subjective diabetes numeracy, respectively, as was its acceptable internal consistency, by a Kuder–Richardson-20 coefficient of .81.
Conclusion: The DHNT demonstrated satisfactory psychometric properties. The instrument with moderate levels of item difficulty may have a lower cognitive burden. The developed instrument can be applied in practice to tailor the education of diabetes self-management as per the levels of health numeracy of specific patients.

Introduction

Diabetes is one of the greatest health problems faced worldwide. About 463 million adults aged from 20 to 79 years have diabetes, and this is estimated to increase to 700 million by 2045 [1]. Most (90–95%) patients have type 2 diabetes [2], and self-management is regarded as a key strategy for their diabetes care [3]. Patients with diabetes need to continuously perform tasks associated with self-management.

The performing of diabetes self-management tasks frequently involves numeric tasks, such as taking medications at the right time, performing an appropriate amount of exercise, computing calories from nutrition labels, interpreting blood glucose levels, calculating insulin doses, and quantifying the risk of getting a disease. These quantitative abilities are reliant on health numeracy [4,5], which is an important concept in practice because patients with lower diabetes-related numeracy have been consistently found to have worse knowledge, self-efficacy, and self-management, and make worse medical decisions [6,7].

Health literacy is the way that people access, understand, appraise, and apply health information to make decisions concerning health care, disease prevention, and health promotion [8].

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Health numeracy is considered to form part of health literacy, and has been defined as "the ability to perform basic reading and numerical tasks required to function in the health care environment" [9]. This perspective was subsequently criticized as inappropriate because health numeracy may provide unique explanations for health outcomes beyond those provided by health literacy [10,11]. Health numeracy has also been simply defined within a narrow scope as the ability to understand and use numbers in daily life [11,12]. However, health numeracy is predominantly defined in a broader perspective, such as going beyond basic arithmetic skills and encompassing the ability to understand, interpret, and apply quantitative, graphical, biostatistical, and probabilistic health information [10,13]. Regarding diabetes, Teft [5] emphasized that health numeracy needs to be broadly defined beyond the simple meaning of a basic understanding of numbers.

The ability to measure diabetes health numeracy is important in both clinical and research applications, but considerable issues remain to be addressed. Based on the transition from the perspective of the term of health numeracy, Nelson et al. [14] proposed the need for instruments reflecting health numeracy from a broader scope. Golbeck et al. [10] similarly suggested that the contents of the instruments need to be expanded based on a comprehensive perspective of the health numeracy. The second issue is choosing between subjective and objective instruments. In a subjective instrument, individuals self-report their perceived levels of health numeracy, such as using Likert scales. In contrast, an objective instrument assesses the ability to process numeric information by asking respondents to answer specific questions, such as about the time to take the next medication. A subjective instrument requires less cognitive effort in responding to questions, whereas an objective instrument assesses health numeracy more accurately [15]. The third issue is related to the lack of psychometric properties. In accordance with a systematic review of measurement properties [16], three objective instruments have been developed for assessing health numeracy for patients with diabetes: diabetes numeracy test-43 (DNT-43) [4], its short-form DNT-15 [17], and brief numeracy [18]. As the results of the systematic review [16], these instruments had no, unclear, or only limited evidence for most of their psychometric properties, implying the need for a new objective instrument measuring health numeracy for patients with diabetes. In addition, a new instrument should be of the disease-specific type because such an instrument is more accurate in the context of clinical practice than using a generic type of an instrument, which is preferable for general healthy people [14,16].

Aim of the study

This study aimed to develop a new objective health numeracy instrument, called the Diabetes Health Numeracy Test (DHNT) and evaluate its psychometric properties in adult patients with type 2 diabetes.

Methods

Phase 1: item generation and content validity

In this study, diabetes health numeracy was conceptualized as the abilities to understand, interpret, and apply health information that requires quantitative skills when performing the tasks for diabetes self-management and treatment based on literature review [10,13,14,19]. Therefore, the three elements considered for item generation were (a) the abilities to understand, interpret, and apply quantitative health information [13,14]; (b) basic, computational, analytical, and statistical aspects of numeric skills [10]; and (c) the tasks required for diabetes treatment and self-management, such as exercise, diet, blood glucose monitoring, taking medications, and foot care [19]. The present study focused on developing an instrument measuring core health numeracy applicable to the majority of adult patients with type 2 diabetes. A national survey found that only 6.8% of patients aged >30 years with type 2 diabetes were treated with insulin injections [20], and so the insulin-injection–related attribute of health numeracy was not included in the present study.

Items were generated using a grid-matrix table combining the aforementioned three elements. The top rows of the matrix contained the abilities to understand, interpret, and apply quantitative health information, whereas the left column contained the tasks for diabetes treatment and self-management. It was then determined which quantitative numeric skills fell under the specific matrix cells crossing rows and columns based on a literature review on diabetes numeracy and discussions with two experts. If an empty cell crossing a row and column was filled with a quantitative numeric skill, the content of the cell was described as an item. This procedure yielded 11 items. Item responses were composited as five-choice answers, including "don't know," and each item was scored as 1 if the answer was correct or 0 if the answer was incorrect or "don't know."

Content validity was evaluated using an item-level content validity index (I-CVI) [21]. A panel of six experts was formed that comprised two diabetes education nurses, one expert on health literacy, two experts on measurement instruments, and one nutritionist. These experts were asked to rate how relevant the initially derived 11 items were to health numeracy in diabetes conditions on the following 4-point scale: 1 = "not relevant," 2 = "somewhat relevant," 3 = "quite relevant," and 4 = "very relevant". The I-CVI was calculated as the proportion of experts who answered that the item was either 3 or 4. If the I-CVI value of an item was >.78 [21], the item was considered to reflect diabetes health numeracy. In addition, the panel was asked open questions that inquired about the comprehensiveness and comprehensibility of the items, such as the use of jargon, reading level, and phrasing ambiguity.

All items satisfied I-CVI = 1.00 with the exception of one item on calculating the time of taking the next medication, for which I-CVI was .50. That item was deleted because it did not satisfy the threshold of .78. In the open questions, the expert panel suggested that two items about "percentage of patients" and two items about "nutrition labels" were asking about similar attributes of health numeracy. One of each item was therefore deleted, and so finally eight items were retained.

Phase 2: pilot test

A pilot test of the content-validated items was conducted with 10 participants who had type 2 diabetes. After the participants had answered the items, a trained research assistant asked questions about whether they had found any sentences or phrases to be difficult to understand. The assistant recorded these difficulties in a logbook.

The participants of the pilot study were aged 55.50 ± 18.15 years, and 80% (n = 8) of them were women. All of them were married and half of them (n = 5) had an education level of high school or a bachelor's degree. Half of them took oral hypoglycemic agents, and their blood glucose level (HbA1c, %) was 7.78 ± 2.11. Four participants reported that they experienced difficulties when answering the items, and one of them described that it felt like taking an examination. The participants considered that the most difficult item was related to nutrition labels, including serving size information, calorie information, percentage of daily intake, nutrition information, and a footnote about recommended daily values. Although the participants experienced these difficulties, the researchers decided to include the item about nutrition labels because they are seen everywhere in daily life. Two participants stated that they experienced no specific difficulty in answering the items.

Phase 3: field testing of psychometric properties

A psychometric evaluation of the DHNT was conducted for structural validity, convergent validity, criterion validity, and internal consistency.

1) Sample and data collection

A convenience sample of 257 participants was recruited at outpatient clinics at 2 university hospitals from May to September 2018. The inclusion criteria for the participants were being diagnosed with type 2 diabetes, aged at least 19 years, and articulate in the Korean language. Participants with gestational diabetes were excluded. Two trained research assistants invited potential participants at outpatient clinics after providing them with a brief description of the purpose of the study. If the participants expressed interest in participating in this study, they were taken to a small private room and provided with more information about the study, such as the voluntary nature of participation and the right to refuse or withdraw from the study at any time. The participants were then asked to sign an informed consent form and to complete a package of questionnaires. The sample size in this study fulfilled the requirements for exploratory factor analysis (EFA), with 7–10 times as many participants as the number of items, and at least 100 participants for the Rasch analysis [22,23].

2) Instruments

The Brief Diabetes Knowledge Test-2 (DKT2) [24] and Numerate Health Literacy, a subscale of the Diabetes Health Literacy Scale (DHLS) [25], were administered to assess the convergent validity and criterion validity of the DHNT, respectively.

Brief DKT2: The DKT2 was developed by the Michigan Diabetes Research and Training Center [24]. Its questionnaire comprises two sections that can be used independently: the first 14 items are applied to adults with diabetes, and the remaining 9 items are relevant to those taking insulin. The present study only used the first section because only adults who did not take insulin were included. Each multichoice item has three or four possible answers, and the responses were scored as 1 point for a correct answer and 0 point for an incorrect answer. The correct answers were summed, with higher scores indicating greater knowledge. The internal consistency of the 14 items was satisfied among a sample of patients with diabetes in the original study, with a Kuder–Richardson-20 (KR-20) coefficient of .77. The English version was translated into Korean using a forward and backward translation technique. Two bilinguals independently translated the original English version into Korean using semantic equivalence. The Korean version (reached consensus by two health professionals) was independently translated back into English by another two bilinguals. Two researchers of this study checked the back-translated versions against the original version. A discrepancy between the translated and original versions was confirmed by the developer of the DKT2. The Korean version of the 14 items exhibited satisfied internal consistency (KR-20 = .70) in this study.

Subjective numeracy: The DHLS was developed to measure diabetes-specific health literacy using a self-reported instrument [25]. The DHLS comprises 14 items scored on a 5-point Likert scale in 3 subscales: informational (7 items), numerate (4 items), and communicative (3 items) health literacy. The DHLS exhibits good psychometric properties for four validity metrics (content validity, structural validity, convergent validity, and criterion validity) and two reliability metrics (internal consistency and test–retest reliability). The numerate health literacy subscale, which subjectively measures diabetes health numeracy, exhibited satisfactory internal consistency (Cronbach's alpha = .85) in the present study. The objective DHNT-based instrument was estimated to be moderately correlated with the subjective diabetes health numeracy as measured using the subjective numeracy subscale [26].

3) Data analysis

Data were analyzed using SPSS for Windows (version 25, IBM Corp., Armonk, NY, USA) and WINSTEPS (Winsteps, Chicago, IL, USA). Correct and incorrect responses to the items were computed using descriptive statistics. For item correlations with binary (dichotomous) responses, a tetrachoric correlations matrix was constructed using TETRA-COM, which provided estimates that were more accurate than those obtained using the commonly used product–moment correlation matrix [27].

To explore underlying factor structure, EFA using unweighted least squares with orthogonal rotation was performed using SPSS, in which the tetrachoric correlation matrix was used as the input for the factor analysis [28]. Before the EFA, Bartlett's test of sphericity and the Kaiser–Meyer–Olkin test were performed to check the factorability of the data [29]. The following criteria were used to determine the number of factors to retain: an eigenvalue greater than 1, a scree plot (one less than the factor number of the inflection point), and at least 50% of the variance explained by the identified factor(s) [30]. Factor loadings with values >.45 were considered meaningful [31].

The structural validity of the DHNT was also assessed using a dichotomous Rasch model (one-parameter item-response-theory model), a series of tests consisting of the item polarity, item fit statistics, and item characteristic curve. Item polarity was examined using the point-measure correlation. The criterion for the correlation coefficient is generally within the range of .3–.8 [32]. Item fit statistics refer to the extent to which items contribute to the same construct and were tested using infit and outfit mean-square fit statistics. Both infit and outfit statistics have an expected value of 1 and an acceptable range of fits from 0.5 to 1.5 [33]. In other words, infit or outfit statistics with values >1.5 (indicating a lack of fit between the items and the model) or <0.5 (suggesting item redundancy) were regarded as indicative of an item that did not fit. In the Rasch analysis, a person's response to a binary item is determined by the respondent's ability and a single item parameter: the item difficulty [34]. These features were depicted in the item characteristic curve, which visualizes how item difficulty is distributed, with the vertical axis indicating the probability of correct answers and the horizontal axis indicating the respondent's ability, with the item difficulty increasing toward the right along the horizontal axis.

Convergent validity and criterion validity were computed using Spearman's correlation. Internal consistency reliability was tested using the KR-20 formula, with a coefficient $\geq$ .70 indicating acceptable reliability [30].

4) Ethical considerations

This study was approved by the institutional review boards of the two university hospitals at which the participants were recruited (Approval no. AJIRB-MED-SUR-15-332 and INHAUH 20180530-05-030). All participants were provided with information about the study, signed an informed consent form, and received remuneration for participating in the study.

Results

Sample

The 257 participants were aged 59.79 ± 12.16 years, and 45.9% were women. Almost three quarters of them reported having completed high school. Most (70.8%) of the participants were taking an oral hypoglycemic agent (Table 1).

Descriptive statistics of items and the tetrachoric correlation matrix

Table 2 indicates that item 6 received the largest proportion of correct answers (71.6%). The tetrachoric correlation matrix indicated that all items had higher coefficients with other items (r_t = .38–.71) with the exception of item 8 (nutrition labels). The coefficients for item 8 were below the criteria of 0.3 for all other items (r_t = .08–.29), and so this item was eliminated due to the small amount of shared common variance [35].

Structural validity

Bartlett's test of sphericity was significant (χ^2 = 1077.16, $p < .001$) and the Kaiser–Meyer–Olkin value (=.85) was good, implying that the data were suitable for factor analysis [29]. Factor analysis extracted a single-factor solution (eigenvalues >1) that accounted for 56.6% of the total variance. The scree plot also exhibited one factor. All items of the DHNT loaded meaningfully at a criterion of >.45 on the factor (Table 2).

From the Rasch analysis (Table 3), the point-measure correlation values for all seven items were positive and within the range of .44–.61, indicating that the items were working in the same direction to measure the single factor. The infit and outfit mean-square values of all items were within the acceptable range of 0.5–1.5. All of the items fit the Rasch model, and so they were all retained. The item difficulty parameters indicated that item 3 was the most difficult and items 5 and 6 were the least difficult (Table 3 and Figure 1). Item difficulty can be interpreted as follows: very easy (lower than −2.0), easy (−0.2 to −0.5), moderate (−0.5 to +0.5), difficult (+0.5 to +2), and very difficult (higher than +2) [36,37]. This meant that the difficulty levels of all items other than item 3 were demonstrated to be moderate for the patients with type 2 diabetes in this study. However, the curves for items 5 and 6 could not be distinguished, reflecting the same item difficulty in a single factor.

Table 1 *General Characteristics of the Study Participants (N = 257).*

Characteristic	*n* (%)	Mean ± SD
Gender		
Men	139 (54.1)	
Women	118 (45.9)	
Age (yrs)		59.79 ± 12.16
<30	5 (1.9)	
30–39	11 (4.2)	
40–49	32 (12.5)	
50–59	66 (25.7)	
60–69	93 (36.2)	
70–79	41 (16.0)	
≥80	9 (3.5)	
Marital status		
Married/living together	201 (78.2)	
Divorced/widow(er)	32 (12.4)	
Unmarried	20 (7.8)	
Other	3 (1.2)	
Data missing	1 (.04)	
Education		
Elementary school	24 (9.3)	
Middle school	40 (15.6)	
High school	112 (43.6)	
College & above	78 (30.3)	
Other	3 (1.2)	
Monthly house income (10,000 KRW)		
<200	87 (33.9)	
200–299	43 (16.7)	
300–399	47 (18.3)	
≥400	74 (28.8)	
Data missing	6 (2.3)	
Disease duration (yrs)		10.83 ± 7.21
Treatment regimen		
Oral hypoglycemic agent	182 (70.8)	
Insulin injection	19 (7.4)	
Oral hypoglycemic agent & insulin injection	52 (20.2)	
No medication	4 (1.6)	
HbA1c (%)		7.62 ± 1.38

Note. HbA1c = Hemoglobin A1c; KRW = South Korean won; yrs = years.

Convergent/criterion validity and internal consistency

The DHNT was moderately correlated with diabetes knowledge (r_s = .40, $p < .001$), indicating that the convergent validity of the DHNT was satisfied. The DHNT was also moderately correlated with diabetes numeracy (r_s = .47, $p < .001$), which also satisfied criterion validity. The KR-20 coefficient for the DHNT was .81, implying the good internal consistency of the scale.

Discussion

This study developed the DHNT comprising seven items to measure health numeracy for patients with type 2 diabetes. The most basic and important process in the development of such an instrument is determining the broadness of the construct covered, based on an identified definition [22]. Existing instruments for measuring diabetes health numeracy have been criticized for mainly covering a basic understanding of quantitative calculations [16]. In contrast, the DHNT was developed in this study with a more comprehensive definition considering the combination of three elements: abilities (understanding, interpreting, and applying quantitative health information), quantitative numeric skills (basic, computational, analytical, and statistical aspects), and tasks (for diabetes treatment and self-management). This comprehensive approach made it more likely that the developed DHNT can more accurately measure diabetes health numeracy.

Structural validity informs how items are combined into a scale or subscale [38]. According to Lee et al. [16], the DNT-15 (scored as binary outcomes of correct or incorrect) is the only instrument whose structural validity has been evaluated in patients with diabetes, and EFA revealed a single-factor solution [4]. Similarly, EFA performed in the present study yielded a single factor for the DHNT. However, a methodologically strong point of the EFA in this study was the use of tetrachoric correlations. For the structural test of a set of binary items, EFA using tetrachoric correlations is a more appropriate procedure (producing less-biased eigenvalues and factor loadings) than the commonly used product–moment correlations [27,39]. The single factor of the DHNT was also confirmed by the absence of any items that did not fit the Rasch model in this study. However, a future study needs to adjust items 5 and 6 to that they have distinct item difficulties. To the best of our knowledge, the DHNT is the first instrument that has been evaluated using both classical test theory (e.g., EFA) and item-response-theory (e.g., Rasch model) for determining its structural validity in measuring diabetes health numeracy.

Convergent validity is tested based on the association between a focal measure (the DHNT in this study) and a comparator instrument with which conceptual convergence is expected [40]. As expected, the DHNT exhibited a moderate correlation with diabetes knowledge in the present study, which is consistent with the findings of previous studies [4,41].

Table 2 *Items and Responses (N = 257).*

Abbreviated item description		Combination of elements for item descriptions			Correct response	Incorrect response
		Task for self-management and treatment	Ability	Numeric skill	*n* (%)	*n* (%)
1.	Calorie consumption	Exercise	Application	Computational	163 (63.4)	94 (36.6)
2.	Weight loss	Exercise	Interpretation	Analytic	177 (68.9)	80 (31.1)
3.	Fasting time	Blood glucose monitoring	Application	Computational	146 (56.8)	111 (43.2)
4.	Table of diagnostic criteria	Diagnosis	Interpretation	Analytic (table)	181 (70.4)	76 (29.6)
5.	Fasting glucose levels[a]	Blood glucose monitoring	Understand	Basic	183 (71.2)	73 (28.4)
6.	Percentage of patients	Disease	Understand	Computational	184 (71.6)	73 (28.4)
7.	Graph of prevalence rates[b]	Disease	Interpretation	Statistical (graph)	168 (63.4)	87 (33.9)
8.	Nutrition labels	Diet	Interpretation	Analytic	40 (15.6)	217 (84.4)

[a] One missing data.
[b] Three missing data.

Table 3 *Results for Structural Validity from Exploratory Factor Analysis and Rasch Analysis (N = 257).*

Abbreviated item description		EFA	Rasch analysis			
		Factor loading	Item difficulty	Infit MNSQ	Outfit MNSQ	PTMEA CORR
1.	Calorie consumption	.72	0.30	1.06	1.12	.50
2.	Weight loss	.83	−0.15	0.85	0.79	.61
3.	Fasting time	.72	0.83	1.06	1.15	.50
4.	Table of diagnostic criteria	.72	−0.29	1.02	1.03	.51
5.	Fasting glucose levels	.65	−0.39	1.15	1.23	.44
6.	Percentage of patients	.83	−0.39	0.84	0.78	.60
7.	Graph of prevalence rates	.74	0.10	0.98	0.98	.54

Note. EFA = exploratory factor analysis; MNSQ = mean-square; PTMEA CORR = point-measure correlation.

The presence of criterion validity implies that a focal measure is consistent with a criterion measuring the same construct [40]. In the present study, the DHNT was moderately correlated with a criterion instrument measuring a subjective diabetes numeracy, as expected. The psychometrics study of Luo et al. [42] measured the generic types of objective and subjective numeracy instruments using the Short Test of Functional health Literacy in Adults–math test [43] and Self-Numeracy Scale-8 [44] in patients with type 2 diabetes, which revealed a weak correlation. In other words, the correlation was stronger when diabetes-specific health numeracy instruments were used than when using generic instruments. This difference in correlation strength may support that a condition-specific instrument is more accurate than a generic instrument in assessments of the health numeracy of people who have a particular medical condition [45].

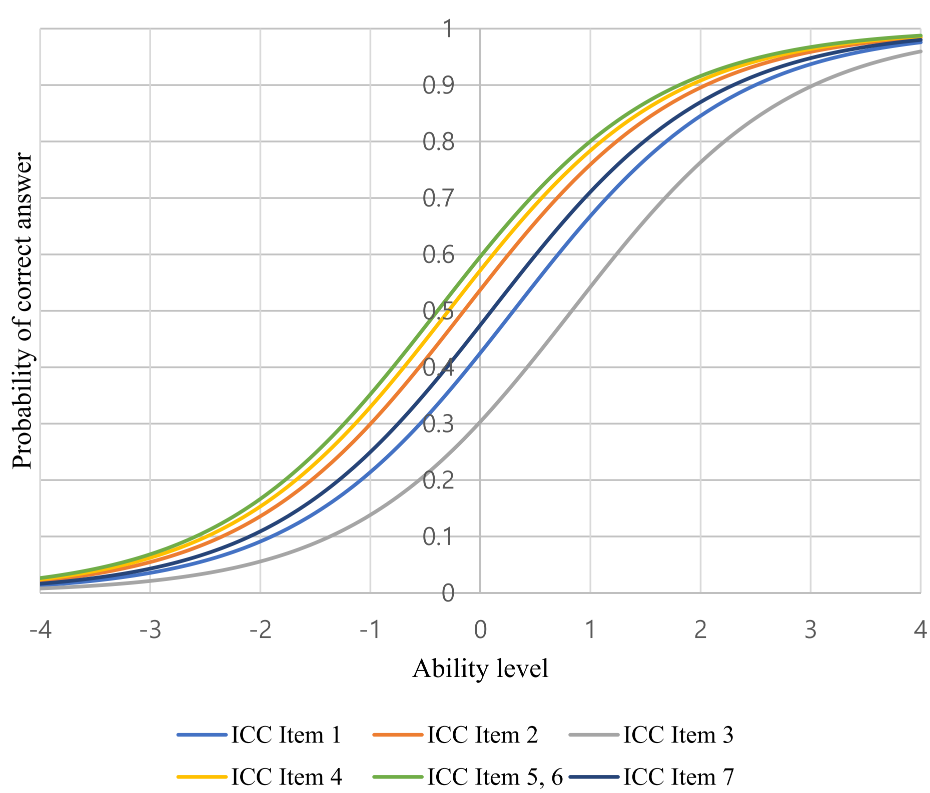

Figure 1. Item characteristic curves (ICCs).

The empirical process of psychometric evaluation performed in this study resulted in the elimination of item 8 about a nutrition label. Some (15.6%) of the participants had correctly answered the item, which had been expected, given that the participants in the pilot test had reported the terms printed on nutrition labels to be more difficult to understand than the numbers on them; that is, considerable levels of both health numeracy and literacy are needed to interpret current nutrition labels. In a similar vein, Rothman et al. [11] emphasized that nutrition labels should be as easy to read and interpret as possible. Those authors suggested that a written explanation should be provided of confusable terms (e.g., the serving size and the number of servings per container) and that extraneous information should be removed (e.g., the percentage of daily intake and the footnote about daily intakes). Therefore, health policy–makers should make efforts to improve the format of nutrition labels to make them easier for consumers to comprehend. Further psychometrics studies should then be applied to the reformatted labels.

Strengths and limitations

The main strength of the DHNT is the potential for its use in practice. The most frequently used instrument for measuring diabetes health numeracy is DNT-43 and its short version, which comprise 43 items and 15 items, respectively [4,17]. The DHNT comprises markedly fewer items than in both of these instruments, which makes it likely to be easier to apply in practice and have a lower burden on the respondents when completing it.

The second strength of the DHNT is that it reflects the rapidly changing medical environment. Health numeracy instruments for chronic diseases (including diabetes) typically contain an item related to calculating the next time to take an oral medication, such as "Take a tablet by mouth every 6 h. If you take one tablet at 8 a.m., when do you take your next tablet?" [18,46]. Technology developments mean that the date and time for taking pills are now printed on the cover of each packet containing a dose of pills when medications are prescribed in the Republic of Korea. This means that patients no longer need to calculate the next time to take medications. The DHNT is consistent with the present medical-care environment in not including such a question; however, the item will need to be rephrased when the instrument is used in a situation or country where such technology is not used.

Objective instruments for measuring health numeracy can induce a burden in respondents that results in them struggling to answer the items [15]. Schapira et al. [13] therefore emphasized the importance of including items with an appropriate level of difficulty. The third strength of the DHNT is that most of its items have a moderate level of difficulty, thereby reducing the response burden and the potential for embarrassment of the respondents.

The responsiveness of an instrument refers to its ability to detect changes over time, and so measuring this requires studies with a longitudinal design [22]. The responsiveness of the DHNT was not tested in the present study, and so it is recommended for future longitudinal studies assess its responsiveness with an intervention to improve numeracy. The test–retest reliability refers to the temporal stability of an instrument over time [22]. This property was also not assessed in the present study, again indicating the need for future studies to verify the stability of the DHNT.

Implications for practice and further research

Self-management is considered a cornerstone of care for patients with diabetes, and education has been emphasized as an important intervention for ensuring practical self-management [47]. Thus, health professionals need to make efforts to provide patients with information on self-management tasks or behaviors and ask them to implement them in their daily lives. The use of DHNT may help health professionals to tailor such education to the levels of health numeracy of individual patients, which should make the education more effective.

The DHNT measures the core contents of health numeracy in adult patients with type 2 diabetes, and so numeracy issues related to insulin injection—which are applicable to relatively few of these patients—were not included in the instrument. Therefore, it is recommended for future studies to develop a numeracy module comprising items specific to type 2 patients treated with insulin injection. The included items could encompass calculation of the insulin dose and the interpretation of the sliding scale for insulin dosages. Such a developed module could then be used in conjunction with the DHNT for patients who receive treatment with insulin injection.

Conclusion

The DHNT is a diabetes-specific health numeracy instrument comprising seven items. It exhibits good measurement properties, in terms of content validity, structural validity, convergent validity, criterion validity, and internal consistency. The items of the DHNT have a moderate level of difficulty, and the shortness of the instrument may make it highly feasible to use in both clinical research and practice. The DHNT can be applied in practice to tailor the education of diabetes self-management depending on the levels of health numeracy of individual patients. Future work could include examining the measurement properties of versions of the DHNT that have been translated into different languages.

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Conflict of interest

The authors have no conflict of interest to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.anr.2020.01.006.

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