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Construction of a quality of life scale for older individuals with neuro-co-cardiological diseases

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Abstract

Purpose This study aimed to develop a Quality of Life (QOL) assessment scale for older patients with Neuro-co-Cardiological Diseases (NCCD) and to evaluate the reliability and validity of the scale.

Method The study participants were derived from the Elderly Individuals with NCCD Registered Cohort Study (EINCCDRCS), a multicenter registry of patients with NCCD. The preliminary testing of the questionnaire was conducted among 10 older individuals aged 65 years and older who had NCCD and were recruited from the registry. Other patients who met the inclusion criteria participated in the field testing. After verifying the unidimensionality, local independence, and monotonicity assumptions of the scale, we employed the Rasch model within Item Response Theory framework to assess the quality of the scale through methods including internal consistency, criterion validity, Wright map, and item functioning differential. Subsequently, we assessed the construct validity of the scale by combining exploratory factor analysis with confirmatory factor analysis.

Results Based on well-validated scales such as the short-form WHOQOL-OLD, HeartQOL, IQCODE, and SF-36, an original Neuro-co-Cardiological Diseases Quality of Life scale (NCCDQOL) was developed. 196 individuals from the EINCCDRCS were included in the study, with 10 participating in the preliminary testing and 186 in the field testing. Based on the results of the preliminary testing, the original questionnaire was refined through item deletion and adjustment, resulting in an 11-item NCCDQOL questionnaire. The Rasch analysis of the field testing data led to the removal of 21 misfitting individuals. The NCCDQOL demonstrated a four-category structure, achieved by combining two response categories. This structure aligned with the assumptions of unidimensionality, local independence, and monotonicity. The NCCDQOL also exhibited good validity and reliability.

Conclusion The revised NCCDQOL questionnaire demonstrated good reliability and validity in the Rasch model, indicating promising potential for clinical application.

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Keywords Neuro-co-cardiological diseases, Multimorbidity, Older, Quality of life, Cognitive, Rasch model

Background

Cardiovascular disease (CVD) is the leading cause of premature death among Noncommunicable Diseases (NCDs) [1]. One-fifth of stroke patients were found to have coronary artery disease [2], and 17.2% of CVD patients were identified as having or developing concurrent cerebrovascular disease (CbVD) [3], which is refer to as Neuro-co-Cardiological Diseases (NCCD) in some studies [4].

Multimorbidity refers to the coexistence of two or more NCDs [5]. In comparison to individuals with a single NCD, those with multimorbidity experience higher mortality and disability rates, increased risk of adverse drug events, lower functional status, and reduced Quality of Life (QOL) [6]. Age is a determining factor for the occurrence of multimorbidity, with the estimated prevalence increasing more than twenty-fold with advancing age [7–10]. Consequently, older adults have been a primary target population for multimorbidity research in clinical practice and previous studies.

In a broad sense, the term NCCD encompasses a range of conditions in which a patient suffers from both cerebral and cardiological diseases. In a narrow sense, NCCD represents a specific subtype of multimorbidity characterized by a linkage between CVD and CbVD based on underlying pathophysiology or similar management concerns [4, 11–13]. Such multimorbidity can lead to cardio-cerebral infarction syndrome and result in severe consequences [2, 14]. Given this background, greater attention should be given to NCCD, particularly among older patients, prompting the development of specific diagnostic and therapeutic approaches and evaluation tools.

QOL assessment scales serve as essential tools for comprehensive evaluation of an individual's health-related status. Widely accepted generic QOL assessment scales include the World Health Organization Quality of Life (WHOQOL), its abbreviated versions (e.g., WHOQOL-100, WHOQOL-BRIEF) [15–18], and the 36-item Short Form (SF-36). Specific scales for the older population include the WHOQOL-OLD, a specialized version of the WHOQOL for older adults, and the Cumulative Illness Rating Scale-Geriatric Version [19, 20]. However, for older individuals with NCCD, who represent a common and significant subset of the multimorbidity population, there is a lack of clarity regarding the specific performance of the aforementioned scales, and there is currently no scale designed specifically for assessing QOL in this population. The aim of this study is to develop a targeted QOL assessment scale tailored to the unique characteristics of older individuals with NCCD.

Methods

Definition of NCCD

This study employed a broad sense definition of NCCD, encompassing the simultaneous presence of at least one CbVD disease, e.g., stroke, Transient Ischemic Attack (TIA), Extracranial Carotid Artery Stenosis (ECAS), Extracranial Carotid Artery Occlusion (ECAO), Intracranial Carotid Artery Stenosis (ICAS), Intracranial Carotid Artery Occlusion (ICAO), Intracranial and Extracranial Multiple Artery Stenosis (IEMAS), Intracranial and Extracranial Multiple Artery Occlusion (IEMAO), Cerebral Aneurysm (CA), Moyamoya Disease (MMD), Dural Arteriovenous Fistula (dAVFs), Intracranial Venous Sinus Thrombosis (CVST), or other CbVD, and at least one CVD, e.g., Ischemic Heart Disease (IHD), Atrial Fibrillation (AF), Heart Failure (HF), Myocardial Infarction (MI), or other related conditions.

Inclusion and exclusion criteria of the study population

Inclusion criteria were as follows: (1) Age>65 years; (2) Diagnosed with NCCD; (3) Able to participate in follow-up and complete the assessment of QOL using self-administered questionnaires independently or with assistance from family members or research personnel.

Construction and administration of the questionnaire

We convened a panel of 7 experts including 4 neurologists, 2 cardiovascular specialists, and 1 linguist, to assess and select items for the questionnaire based on the characteristics of the target population. The initial version of the NCCDQOL questionnaire was developed using the computational results from the short-form WHOQOL questionnaire for older adults (WHOQOL-OLD) [21]. We evaluated the items based on their quality, translated understandability, and relevance to individuals with NCCD [22]. After evaluation, a voting process was conducted to select the most suitable items. For the overall assessment of QOL in older adults, we considered the SF-36 [23] as a supplementary item pool. As a complement to NCCDQOL for specific NCCD diseases, we referred to the items from HeartQOL [24] and the short-form Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE) [25]. After selecting the items, the discussion group further reduced the inappropriate items based on the cultural background, feasibility, and respondent burden of the survey population. Since there is no official Chinese version of the WHOQOL-OLD questionnaire, the translation and localization of the items in the short-form WHOQOL-OLD were performed within the discussion group.

Preliminary testing of the questionnaire

The preliminary testing of the questionnaire was conducted among a sample of 10 older individuals with NCCD. These 10 patients were derived from patients with good adherence in the initial collection of field testing and were individually created as a pretest cohort. The participants were asked to complete the preliminary version of the NCCDQOL questionnaire. They were also interviewed to assess their understanding of each item and the perceived importance of each item in relation to their daily lives. Items that were deemed difficult to understand or were considered less important were either excluded or modified.

Field testing of the questionnaire and item reduction

Following the pretesting phase, multicenter field test was conducted within the Elderly Individuals with Neuro-co-Cardiological Diseases Registered Cohort Study (EINCCDRCS). A prospective registry was established from June 2022 to April 2023, including older patients with multimorbidity of cardiovascular and cerebrovascular diseases who were admitted to the cardiology departments at the First Hospital of Hebei Medical University, the First Affiliated Hospital of Henan University of Chinese Medicine, Tianjin Medical University General Hospital, and the Fuwai Hospital Chinese Academy of Medical Sciences, as well as the neurology department at Beijing Sanbo Brain Hospital. From this cohort, patients who met the diagnosis criteria for older patients with NCCD were selected for inclusion in the study. All enrolled patients provided informed consent and were requested to complete three QOL assessments (NCCDQOL, WHOQOL-BREF, and SF-36). We have reported on this study in a recently published article related to NCCD QOL research in older individuals [26].

Item reduction and field testing were conducted using item response theory. The scoring was based on the positive items, where higher scores indicated better QOL. For the negatively worded items, the scoring was reversed during calculation [27]. Two steps were employed to analyze the quality of the testing. First, the overall quality of the questionnaire was examined by analyzing the correlation between two similar but differently worded questions. Second, using the person fit module in Winsteps [28], the goodness of fit of the patients was analyzed. If the person outfit was >3, it indicated person misfit, and the patient was excluded.

Validation and quality assessment of the questionnaire

Hypothesis testing and Rasch analysis were conducted using Winsteps 5.5.0. Prior to Rasch analysis, hypothesis testing was performed to evaluate the assumptions of unidimensionality, local independence, and monotonicity of the questionnaire.

In the quality assessment analysis, we first evaluated person fit. Due to the small sample size (<200), outfit mean square (MnSq) > 2.0 was primarily used for screening [29]. Patients with outlier values in these measurements were considered misfit persons.

Next, we evaluated the item fit. The mean square (MnSq) reflects the degree of contribution of the items to the measurement model. The infit MnSq is an inlier pattern-sensitive fit statistic, which is more sensitive to unexpected patterns of observations, whereas the outfit MnSq is an outlier-sensitive fit statistic, which is more sensitive to unexpected values of observations. The ideal MnSq value was 1.0, reflecting no unexpected variance in the responses to the item [21]. Items outside the standard range were considered mismatches.

Criterion validity was assessed by correlating the total scores of NCCDQOL with those of WHOQOL-BREF and SF-36. A correlation > 0.7 is generally considered the threshold for criterion validity [30]. The Wright map can be used to evaluate how well the items of the survey (or test) define the trait and assess the strengths and weaknesses of the survey instrument [31]. The evaluation of Rasch model analysis results is based on the Rating Scale Instrument Quality Criteria [32].

Differential Item Functioning (DIF) occurs when people from different groups with the same latent trait have a different probability of giving a certain response on a scale [33]. $|DIF| \geq 0.64$ logits and $p \leq 0.05$ (2-sided) indicate bias in QOL among different groups.

Ceiling and floor effects are considered present when more than 15% of patients in the overall group and each diagnostic group report the lowest score (=0; floor) or the highest score (=5; ceiling) [30].

The internal consistency of the questionnaire was evaluated using Cronbach's alpha [34], with values between 0.7 and 0.95 indicating good internal consistency. Item-total correlations < 0.325 were considered for removal, as they contribute little to discriminating between respondents [35]. IBM SPSS Statistics 21 software was used for the analysis.

Confirmatory Factor Analysis (CFA) is a measurement model based on structural equation modeling, used in this study to assess construct validity. We employed five adaptability indices to ascertain whether CFA supports the factor structure: the chi-square to degrees of freedom ratio ($\chi 2/df$) < 5, Comparative Fit Index (CFI) > 0.90 [36, 37], Goodness of Fit Index (GFI) > 0.80, Adjusted Goodness of Fit Index (AGFI) > 0.80, and Root Mean Square Error of Approximation (RMSEA) < 0.10 [38]. CFA analysis was conducted using IBM SPSS Amos 25.

Exploratory Factor Analysis (EFA) is a multivariate statistical method used to modify the factor structure of scales [39]. In this study, when the factor structure could not be determined solely through CFA, EFA was

employed to modify the factor structure before conducting CFA [40].

Some of the methodologies employed in this research were previously introduced in our concurrently conducted study, which focused on aspects parallel to the current investigation [26].

Results

Figure 1 presents the flowchart of the current study. A total of 363 patients from the EINCCDRCS were enrolled in this study. All 363 patients signed informed consent forms. Forty-two patients were excluded due to age < 65 years, and 46 patients were excluded due to inability to confirm the diagnosis of NCCD. 10 patients (age = 71.9 ± 5.5, male/female = 4:6) participated in the preliminary testing through structured interviews. Among the remaining 265 patients, 186 patients completed the NCCDQOL questionnaire.

Construction of the initial scale

The initial version of NCCDQOL selected OLD-01, OLD-11, OLD-6, OLD-12, OLD-17, and OLD-21 (items of the WHOQOL-OLD questionnaire are numbered from OLD-1 to OLD-24) based on the short-form WHOQOL-OLD. For the short-form IQCODE, five items were selected based on the aspects covered. In the case of HeartQOL, a comprehensive item summarizing the specialized items for IHD was included. During the preliminary testing, patients expressed discomfort with the question related to death and dying, leading to the removal of OLD-06. Some patients found OLD-11 confusing, stating that the content in the question was not specific enough. Therefore, four items related to patients' self-care abilities from the Physical Functioning facet of SF-36, which closely resembled the autonomy facet, were included as replacements. Additionally, based on the feedback regarding patient understanding during the preliminary testing, significant adjustments were made to OLD-17 and OLD-21. The revised initial version of the questionnaire consisted of seven domains and 16 items (Supplementary material 1). NCCD-11 was a reverse item of NCCD-5, included for quality control purposes to assess response consistency.

Preliminary evaluation of the questionnaire in the field test

After the initial version of NCCDQOL was built, we conducted field tests. For quality control, the fifth and eleventh items showed a highly correlated Person fit ($p < 0.001$) after reversing the score for the eleventh item. Among the three QOL quality assessment questionnaires completed, the overall missing rate for items was 0.15%, with no item exceeding a 2% missing rate. The Cronbach's alpha was 0.904, indicating good internal consistency among the items. The Wright maps illustrate the relationship between participants' QOL and item difficulty across NCCDQOL, SF-36, and WHOQOL-BREF (Fig. 2a, c, and d).

Item reduction and adjustment

Due to the observed overall low difficulty level of the items in the initial version of the NCCDQOL, as indicated by the Wright map (Fig. 2a), and the presence of floor effects throughout the entire scale, we conducted item reduction. Since most items met the quality criteria, we primarily relied on the results of construct validity analysis to guide the item reduction process. To ensure the scale's consistency and reduce the burden on patients in completing the questionnaire, we decided to retain only one item per facet that performed well in the Rasch analysis. Ultimately, we removed the majority of items with low difficulty levels (item logit) identified in the Rasch analysis (item-4, item-5, item-10, item-11, item-12, item-13, item-15). In the Inter-item Correlation Matrix (Fig. 3a), there was a high correlation of 0.93 between item-2 and item-3, indicating multicollinearity. Although one of these items could have been deleted to address the multicollinearity issue, we decided to remove the entire facet B due to our concerns about the ambiguity of these two items and their unsuitability as standalone items in the scale, considering their original placement in the SF-36. Additionally, we included a global index (NCCD-1) to reflect the disparate values and preferences of individual patients and offer investigators a more comprehensive approach to measuring QOL [41].

After the aforementioned steps, a new NCCDQOL scale (Supplementary Material 2) was developed. It includes six domains: Global Index, Sensory Abilities, Physical Functioning, Past, Present, and Future Activities, Social Engagement, Intimate Relationships, Cognitive Functioning, and Psychological Well-being.

Rasch analysis

Hypothesis testing

Unidimensionality Unidimensionality for the original five-category structure was first examined. As shown in Table 1, the principal component analysis of the residual showed that the Rasch dimension explained 52.3% (> 40%) of the variance in the data, with an eigenvalue of 2.6, and accounted for 11.4% of the unexplained variance. The variance in the data explained by Rasch measures was more than four times the variance explained by the largest secondary dimension. The overall results indicated that the data satisfied the assumption of the Rasch model [32].

Local independence As shown in Table 2, none of the items breached the 0.50 limit (Davidson, Keating, & Eyres, 2004; Ten Klooster, Taal, &van de Laar, 2008), and most of

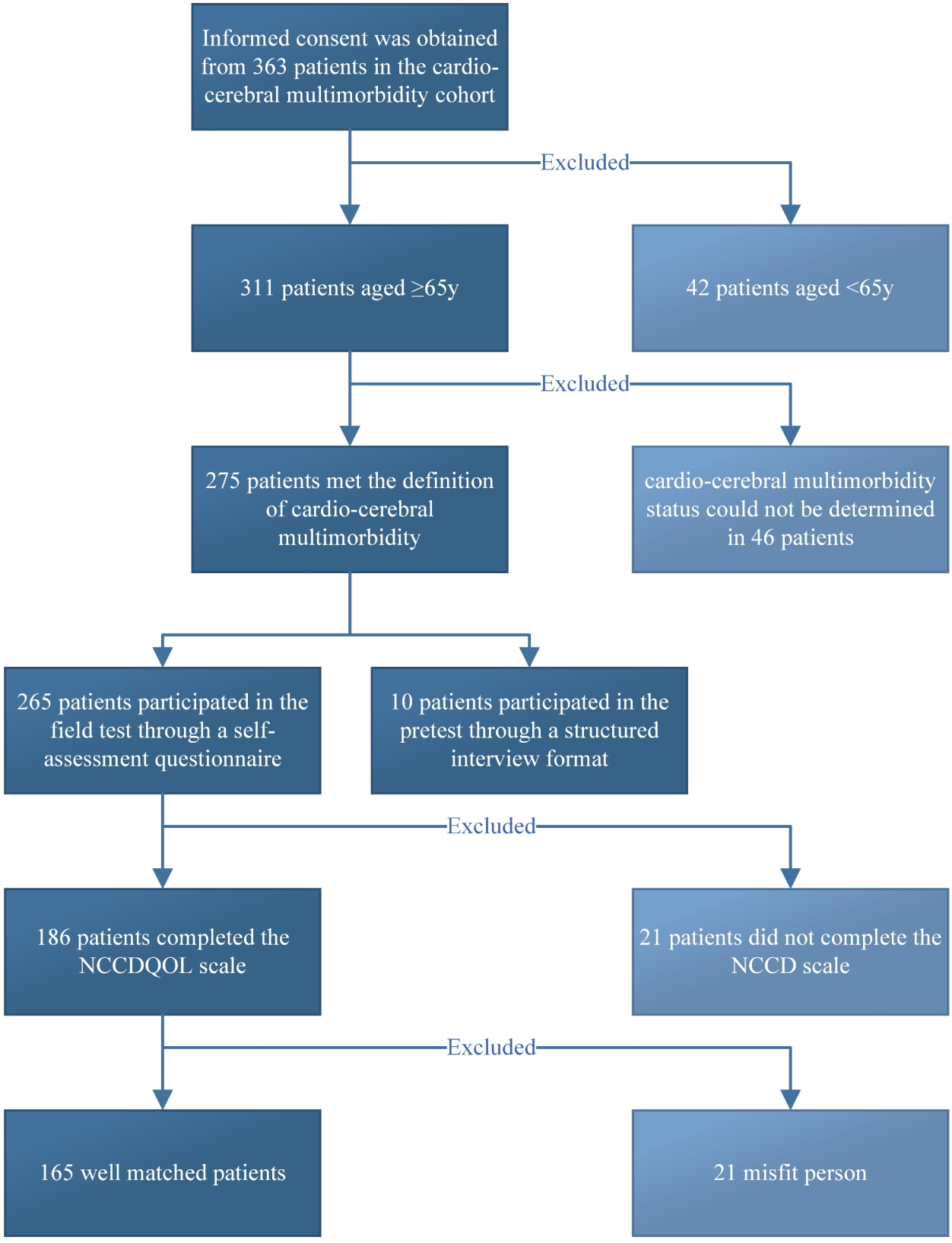

Fig. 1 Patient inclusion, exclusion, and mismatched participant removal process

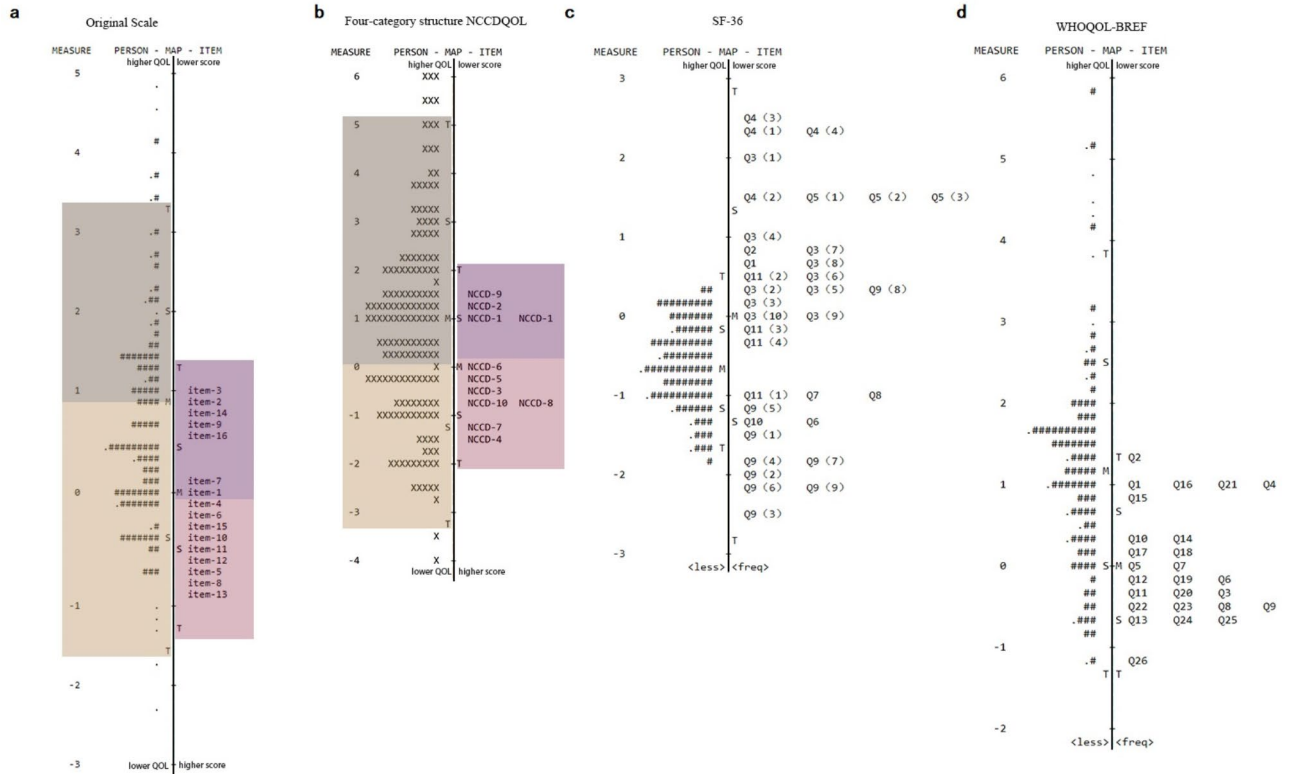

Fig. 2 Wright maps of the original scale. (**a**), the four-category structure NCCDQOL (**b**), the SF-36 (**c**), and the WHOQOL-BREF (**d**). The left side of the vertical axis in the Wright maps illustrates the distribution of patients' quality of life (QOL) scores, with the top representing high QOL and the bottom representing low QOL. On the right side of the vertical axis, the distribution of item difficulties is displayed, with the top indicating high difficulties and the bottom indicating low difficulties (representing easier attainment of low scores to easier attainment of high scores). In (**a**) (**c**) and (**d**), each "#" represents two patients, and each "." represents one patient. In (**b**), each "X" represents one patient. "M" denotes the mean of patient QOL or item difficulties, "S" represents the variance, and "T" indicates twice the variance

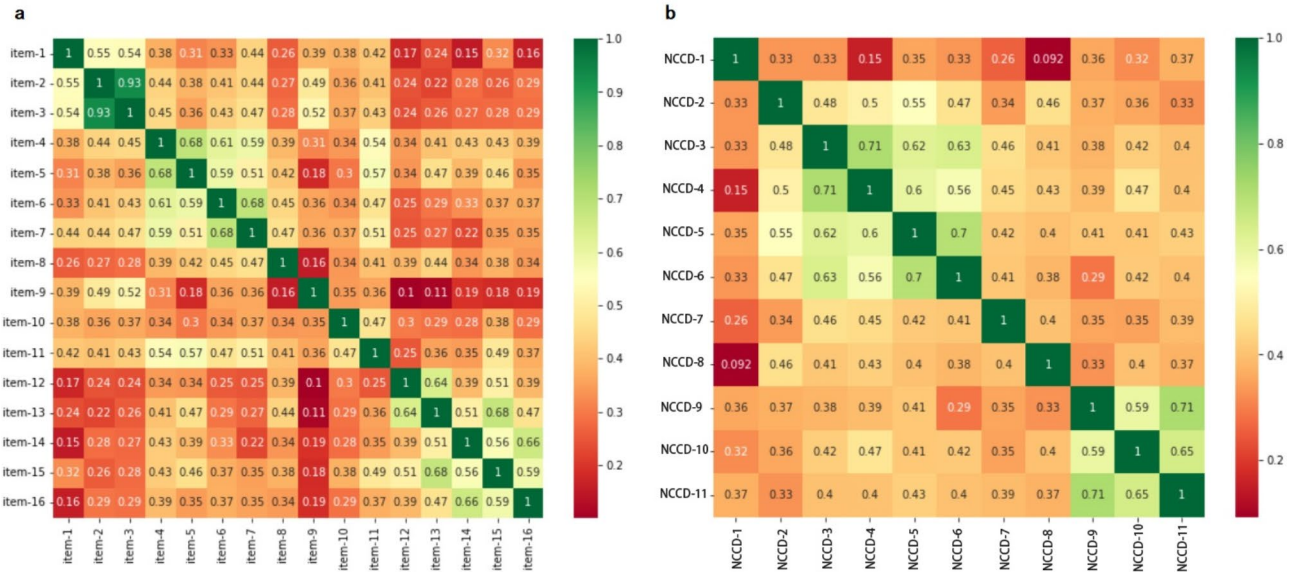

Fig. 3 Heatmap of the inter-item correlation matrix for the original scale. (**a**) and the four-category structure NCCDQOL (**b**)

Table 1 Unidimensionality

	Eigenvalue	Observed	Expected
Total raw variance in observations	23.0438	100.00%	100.00%
Raw variance explained by measures	12.0438	52.30%	51.10%
Raw variance explained by persons	8.5475	37.10%	36.30%
Raw Variance explained by items	3.4964	15.20%	14.80%
Raw unexplained variance (total)	11	47.70%	48.90%
Unexplained variance in 1st contrast	2.616	11.40%	
Unexplained variance in 2nd contrast	1.6207	7.00%	
Unexplained variance in 3rd contrast	1.3493	5.90%	
Unexplained variance in 4th contrast	1.2518	5.40%	
Unexplained variance in 5th contrast	0.9171	4.00%	

Table 2 Local independence

Correlation	Entry number item	Entry number item
0.37	3 NCCD-3	4 NCCD-4
0.34	9 NCCD-9	11 NCCD-11
0.26	5 NCCD-5	6 NCCD-6
0.23	10 NCCD-10	11 NCCD-11
-0.46	6 NCCD-6	9 NCCD-9
-0.37	2 NCCD-2	11 NCCD-11
-0.35	5 NCCD-5	9 NCCD-9
-0.33	2 NCCD-2	10 NCCD-10
-0.33	5 NCCD-5	11 NCCD-11
-0.32	3 NCCD-3	11 NCCD-11
-0.30	2 NCCD-2	9 NCCD-9
-0.29	6 NCCD-6	11 NCCD-11
-0.29	1 NCCD-1	4 NCCD-4
-0.28	6 NCCD-6	10 NCCD-10
-0.28	5 NCCD-5	10 NCCD-10
-0.26	3 NCCD-3	10 NCCD-10
-0.25	4 NCCD-4	11 NCCD-11
-0.24	7 NCCD-7	10 NCCD-10
-0.22	1 NCCD-1	8 NCCD-8
-0.22	3 NCCD-3	9 NCCD-9

the correlations between items were between 0.2 and 0.4, indicating item independence in the instrument.

Monotonicity Table 3 shows the results of the monotonicity analysis for both versions of NCCDQOL. Most of the criteria (Linacre, 2022) in the original scale are satisfied. There are enough observed frequencies in each category, the average measure increases monotonically along the categories, and infit and outfit for all categories are below 2.0. However, the thresholds are not completely

Table 3 Monotonicity

Categorization	Observed Count	Observed avrge	Infit MNSQ	Outfit MNSQ	Andrich threshold
Original (12345)					
1	67	-0.95	1.19	1.18	NONE
2	475	-0.43	0.93	0.93	-2.7
3	338	0.21	1.14	1.34	0.26
4	835	1.11	0.87	0.9	-0.25
5	316	2.49	0.99	1.02	2.69
Four-category (12234)					
1	67	-1.56	1.27	1.16	NONE
2	813	-0.4	0.96	1.01	-3.63
3	835	1.39	0.85	0.86	0.48
4	316	3.07	1.06	1.07	3.15

monotonically increasing, and the distance between categories 3 and 4 is not large enough to describe distinct ranges on the variable, suggesting that the participants did not reliably distinguish between categories. It can be seen more visually in Fig. 4a that category 3 is the least likely to be used, resulting in disordered step values. Therefore, the original scale's category 3 was collapsed with adjacent category 2, and then the data were reanalyzed to compare various rating scale categorizations. In the four-category structure, each category is fully utilized (Fig. 4b), the thresholds are monotonically increasing, and the distances are large enough to describe distinct ranges for the variable. The other indicators of the four-category structure still performed well, so we adopted this model, and proceeded with the analysis.

Person misfit In the person fit measurement, we found a total of 21 out of 186 patients (11.3%) with abnormal measurements. We considered these 21 as misfit persons and excluded them from the subsequent analysis. The results of item measurement for NCCDQOL are shown in Table 4. MnSq was within (0.5-2.0), which means that these items performed satisfactorily in the potential noise features.

Figure 5a displays the baseline data, types of NCDs, and the number of NCDs diagnosed in the 165 participants. The average age of the participants was 71.9 (±5.5) years, and 104 (63.0%) were male. The main cerebrovascular disease reported was stroke (72%), while the main CVDs were IHD (63%) and MI (24%). Figure 5b shows the completion status of the four-category structure NCCDQOL.

Criterion validity

For the WHOQOL-BREF, questionnaires with complete missing data or overall missing data ≥ 20% were excluded when calculating average scores. Following the methodology outlined in the WHOQOL-BREF User Manual [27], we performed data imputation, reverse scoring for

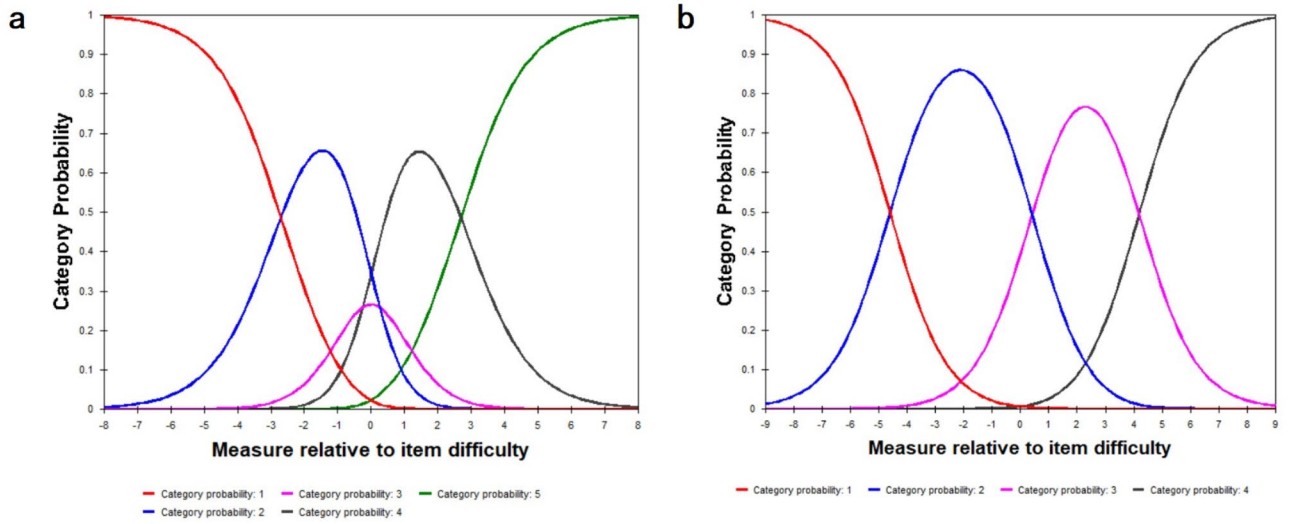

Fig. 4 Category probability curves of the original scale. (**a**) and the four-category structure NCCDQOL (**b**). The X-axis symbolizes the latent trait of coping, and the y-axis represents the probability of the category being selected

Table 4 Summary statistics of item measure in Rasch analysis

Construct and Item Number	Total Score	Total Count	Measure (Logits)	Model S.E. (Logits)	Infit MNSQ	Outfit MNSQ	*P.* M. Corr.
NCCD-9	379	164	1.54	0.17	1.18	1.13	0.66
NCCD-2*	389	164	1.26	0.17	0.82	0.77	0.68
NCCD-1	384	159	1.12	0.17	1.53	1.65	0.55
NCCD-1	397	164	1.04	0.17	1.68	1.65	0.76
NCCD-6	434	165	0.11	0.16	0.79	0.77	0.77
NCCD-5	447	165	-0.23	0.16	0.66	0.64	0.79
NCCD-3	455	164	-0.53	0.16	0.81	0.78	0.79
NCCD-8*	463	164	-0.72	0.16	0.88	0.99	0.64
NCCD-1	462	163	-0.77	0.16	1	1.01	0.78
NCCD-7	489	165	-1.32	0.16	0.82	0.82	0.68
NCCD-4	495	165	-1.48	0.16	0.74	0.73	0.77
MEAN	504.6	187.8	0	0.14	1	1	
P.SD	44	1.6	0.81	0	0.3	0.3	

Items marked with * are reverse items. The total score is the total number of points answered by all patients in each item. The total count is the total number of patients who answered the item counting the missing items. Measure is the item measure of the Rasch model using logit units. Model S.E. is the standard error of the item measure in logit units. P. M. Corr is the Pearson product-moment correlation coefficient

reverse-coded items, and calculated domain scores. In the case of the SF-36, questionnaires with complete missing data or overall missing data ≥ 50% for each dimension were excluded. Score conversions, reverse scoring, and calculation procedures were conducted based on the SF-36 development manual [23]. In instances where the manual did not provide specific guidelines for handling missing data, we imputed missing data by calculating the average score of other items within the same domain. For the four-category structure NCCDQOL, questionnaires with complete missing data or overall missing data ≥ 20% were excluded. Since the NCCDQOL has fewer items per domain, missing data were imputed by calculating the average score of all other items. The total score was computed as the sum of all items. We examined the correlation between the NCCDQOL and the other two questionnaires' total scores. The NCCDQOL showed a person correlation of 0.645 ($p < 0.001$) with the WHO-QOL-BREF and a person correlation of 0.704 ($p < 0.001$) with the SF-36.

Reliability, separation and strata

Person reliability indices include the person reliability coefficient, interpreted as the replicability of the person ordering, and the person separation index, which identifies the number of statistically distinct ability strata of the individuals in the sample [42]. Item reliability is the consistency of a set of items, that is, to what extent they measure the same thing, and item separation is used to verify the item hierarchy, revealing how well a sample of people is able to separate the items [43, 44].

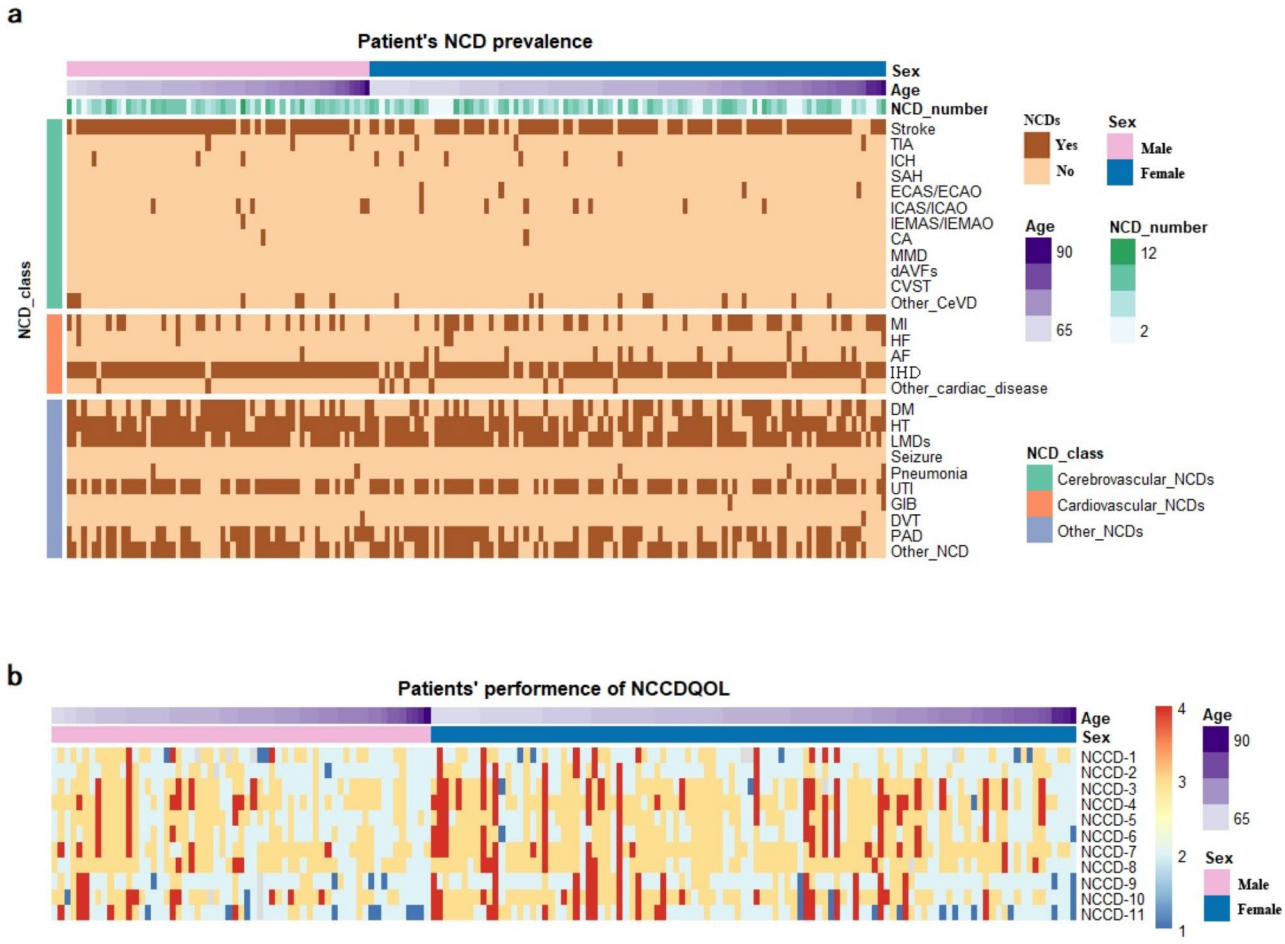

Fig. 5 Summary of baseline data (**a**) and questionnaire response results (**b**). The X-axis represents each patient. Abbreviations: cerebral infarction, Extracranial carotid artery stenosis (ECAS), Extracranial carotid artery occlusion (ECAO), Intracranial Carotid Artery Stenosis (ICAS), Intracranial carotid artery occlusion (ICAO), Intracranial and Extracranial Multiple Artery Stenosis (IEMAS), Intracranial and Extracranial Multiple Artery Occlusion (IEMAO), Cerebral Aneurysm (CA), Moyamoya Disease (MMD), Dural Arteriovenous Fistula (dAVFs), Intracranial Venous Sinus Thrombosis (CVST), Cerebrovascular Disease (CbVD), Hypertension (HT), Lipoprotein Metabolism Disorders (LMDs), Diabetes Mellitus (DM), Atrial Fibrillation (AF), Heart Failure (HF), Myocardial Infarction (MI), Seizure, Pneumonia, Urinary Tract Infection (UTI), Gastrointestinal Bleeding (GIB), Deep Vein Thrombosis (DVT), Ischemic Heart Disease (IHD), Peripheral Arterial Disease (PAD)

Separation index values can range from 0 to infinity, and higher values indicate better separation [43]. Item separation indices of 3 or greater are desirable [29]. In terms of person separation, an index of 1.50 is acceptable, 2.00 is good, and 3.00 is excellent [45].

Based on the results of the Rasch analysis reported for the four-category structure NCCDQOL scale, the reliability coefficients were found to be 0.88 (person) and 0.97 (item). According to the criteria [32], these results indicate excellent (>0.94) and good (0.81–0.90) reliability for persons and items, respectively. Moreover, the separation indices were found to be 2.75 (person) and 5.83 (item), indicating that the scale items were able to distinguish the person's QOL and that the person was able to respond adequately to the scale items.

The number of ability strata that can be resolved is provided by the formula (4*Separation+1)/3 with the assumption that different ability levels are 3 standard errors apart [46]. The person strata are 4.00, which enables the distinction of five strata of a person's QOL (high, above average, moderate, below average, low). The item strata are 8.11, which enables the distinction of nine groups or strata.

Respondents' ability and item difficulty

Figure 2b shows the number of respondents' ability and item difficulty on the logit scale. All the items are scattered and point toward the diversity of respondents' abilities. The item mean is set by default at 0.00 logit to ensure that each group of persons has a 50:50 chance of success in responding to the item that matches their ability [47]. Meanwhile, the person mean is at 0.88 logit, which means that the items in this sample are good targeted (<1.0 logit). The item difficulty measures range

Table 5 Differential item functioning in demographics and chronic diseases

Demography aspect	Item	Detail	DIF contrast	t	Chi-squ	*p*
Sex	NCCD-1	Male–Female	-0.8	-2.71		0.008
Age	NCCD-3	A-B	0.68		8.5547	0.003
	NCCD-11	A-B	-1.92		6.3542	0.012
Hypertension	NCCD-11	No-Yes	0.75		2.13	0.037
Atrial fibrillation	NCCD-1	No-Yes	1.54	2.38		0.041
	NCCD-11	No-Yes	-1.47	-2.53		0.027
Dyslipidemia	NCCD-6	No-Yes	0.62	2.05		0.043
	NCCD-7	No-Yes	-0.71	-2.45		0.016
	NCCD-9	No-Yes	-0.67	-2.2		0.029
Urinary system infection	NCCD-7	No-Yes	-0.59	-2.07		0.041
	NCCD-10	No-Yes	0.62	2.15		0.034
Myocardial infarction	NCCD-1	No-Yes	0.91	3.07		0.003
	NCCD-7	No-Yes	0.6	2.11		0.036

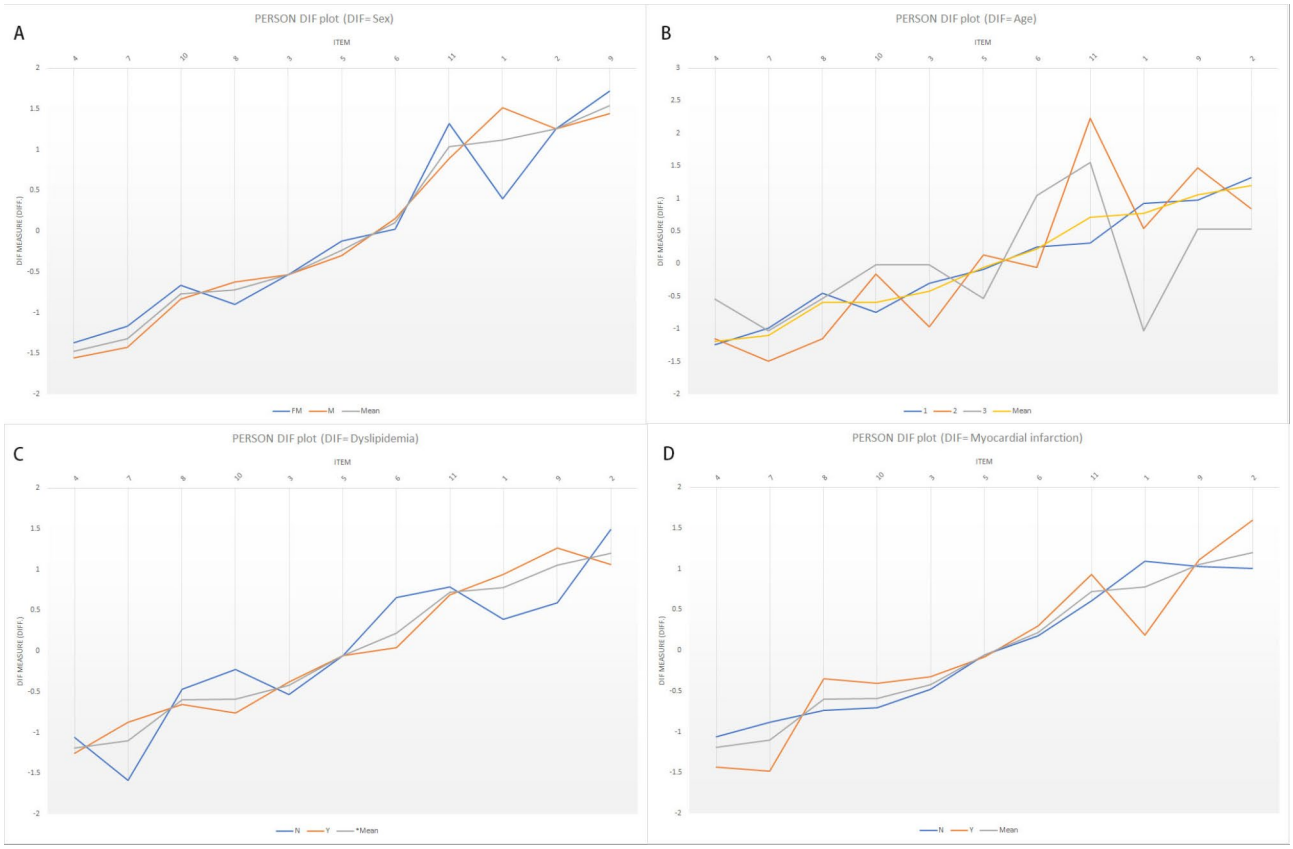

Fig. 6 Differential item functioning within the NCCDQOL scale. (**a**) Gender subgroup; (**b**) Age subgroup (1 = 65–74, 2 = 75–84, 3 = 85-); (**c**) Subgroup with dyslipidemia; (**d**) Subgroup with myocardial infarction

from +1.54 to -1.48 logit with a spread of 3.02 logit. Meanwhile, the person's QOL estimates ranged from 6.03 to -4.00. Patients with a higher QOL were at the top of the map, while those with a lower QOL were at the bottom of the map.

Differential item functioning

As shown in Table 5, NCCD-1 has been found to be biased in some demographic statistics and whether there is AF or MI. For example, women are more likely than men to give themselves higher ratings when responding to the question, "How would you rate your quality of life?" in NCCD-1. Similar biases also appear in NCCD-3, NCCD-6, NCCD-7, NCCD-9, NCCD-10, and NCCD-11. Figure 6 shows the performance of these items that appear as DIFs in different groupings.

Cronbach's alpha

The Cronbach's alpha = 0.89 for the post item reduction NCCDQOL indicates that the scale has high reliability. The item–total correlations for all items > 0.325 indicate good internal consistency of the scale (Table 6). Figure 3b shows the correlation matrix of the post item reduction NCCDQOL, and it can be seen that the correlations between the items are within the range of appropriateness, except for the low correlation between NCCD-1 and NCCD-4 and NCCD-8.

Factor analysis

Due to the insufficient number of items in each domain of the revised NCCDQOL scale to support CFA analysis, we initially conducted an exploratory factor analysis. The Kaiser-Meyer-Olkin (KMO) value of 0.886 indicated good intercorrelations among variables, while Bartlett's test of sphericity showed significance ($P < 0.0001$), supporting the assumption of independence among variables. As shown in Table 7, EFA yielded two primary components, where items NCCD-1 to NCCD-8 loaded heavily on Component 1, while items NCCD-9 to NCCD-11 loaded heavily on Component 2. Component 1 represented general QOL indicators, whereas Component 2 represented QOL indicators related to cognitive functioning. Consequently, based on the results of EFA, we recombined items NCCD-1 to NCCD-8 from Component 1 into a single "General QOL" domain.

Table 6 Reliability analysis of the original and post item reduction scales

Reliability Statistics	**Cronbach's Alpha**	**Cronbach's Alpha Based on Standardized Items**	***N* of Items**		
Original NCCDQOL					
	0.904	0.908	16		
Post-item reduction NCCDQOL					
	0.888	0.890	11		
Item-Total Statistics	**Items**	**Scale Mean if Item Deleted**	**Scale Variance if Item Deleted**	**Corrected Item-Total Correlation**	**Squared Multiple Correlation**	**Cronbach's Alpha if Item Deleted**
Original NCCDQOL						
	item-1	51.85	103.542	0.507	0.423	0.901
	item-2	52.48	101.425	0.619	0.880	0.897
	item-3	52.56	100.965	0.632	0.883	0.897
	item-4	51.72	100.008	0.691	0.602	0.895
	item-5	51.39	103.369	0.643	0.610	0.897
	item-6	51.78	103.358	0.644	0.589	0.897
	item-7	51.94	102.100	0.636	0.598	0.897
	item-8	51.37	107.810	0.540	0.378	0.901
	item-9	52.32	105.601	0.430	0.357	0.904
	item-10	51.56	106.106	0.523	0.335	0.901
	item-11	51.50	103.534	0.656	0.520	0.897
	item-12	51.51	104.186	0.490	0.458	0.902
	item-13	51.34	103.237	0.585	0.624	0.899
	item-14	52.44	101.259	0.560	0.540	0.900
	item-15	51.68	100.349	0.650	0.618	0.896
	item-16	52.35	98.499	0.570	0.543	0.900
Post-item reduction NCCDQOL						
	NCCD-1	27.17	26.642	0.413	0.306	0.890
	NCCD-2	27.29	25.765	0.593	0.432	0.879
	NCCD-3	26.85	24.596	0.695	0.619	0.872
	NCCD-4	26.62	25.202	0.671	0.616	0.874
	NCCD-5	26.95	25.105	0.706	0.607	0.872
	NCCD-6	27.02	25.289	0.656	0.585	0.875
	NCCD-7	26.63	26.643	0.545	0.321	0.882
	NCCD-8	26.79	26.510	0.518	0.358	0.883
	NCCD-9	27.25	24.813	0.622	0.578	0.877
	NCCD-10	26.78	24.639	0.649	0.514	0.875
	NCCD-11	27.15	23.312	0.654	0.612	0.877

Table 7 Rotated component matrix

Items number	Component	
	1	2
NCCD-1	0.462	
NCCD-2	0.657	
NCCD-3	0.817	
NCCD-4	0.774	
NCCD-5	0.784	
NCCD-6	0.797	
NCCD-7	0.620	
NCCD-8	0.629	
NCCD-9		0.881
NCCD-10		0.703
NCCD-11		0.833

Note: Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization. Factor loadings smaller than 0.45 were not displayed

As illustrated in Fig. 7, we conducted CFA based on the redefined two-domain structure derived from EFA results. Table 8 demonstrates that all parameters meet the criteria, affirming the robust structural validity of NCCDQOL.

Discussion

During the development and testing of the questionnaire, the recruitment of participants took place in centers under strict control due to the COVID-19 pandemic. Therefore, we aimed to minimize the additional burden on patients and healthcare workers caused by the questionnaire survey. The length of a questionnaire plays a crucial role in survey outcomes [48], and many studies have reported higher response rates with shorter self-report questionnaires, whether administered via postal mail or electronically [49, 50]. In a study conducted by Kost et al. in 2018, which included three different lengths of questionnaires (Ultrashort, Short, and Long-Research Participant Perception Surveys), the Ultrashort version consisting of 13 questions showed the highest response rate [51]. Additionally, using long questionnaires raises concerns about participant disinterest, which may impact the quality of survey results [52]. Therefore, after discussion within the research group, we decided to use the Ultrashort version and limit the questionnaire length to 15 items or fewer.

While the design goal of this questionnaire was not specifically for older Chinese patients with NCCD, the localization process accounted for the cultural background since the testing was conducted in China. Chinese individuals, especially older Chinese individuals, are generally reluctant to discuss death [53, 54]. Therefore, we did not include questions related to death, even though this topic may be important for assessing QOL in older individuals. Furthermore, the culturally nuanced context of Chinese people might make it difficult for older individuals to comprehend and discuss abstract concepts such as intimate relationships and love. Therefore, we modified these topics to more concrete questions (NCCD-7: I have sufficient communication with my family and friends).

Cognitive impairment is closely related to the QOL of individuals with multimorbidity, affecting the severity of illnesses and increasing the burden of disease, particularly in the context of multimorbidity with neurological disorders [55–60]. Moreover, incorporating items related to cognition can help identify patients with poor cognitive status and reduce biases in questionnaire analysis.

No ceiling or floor effects were observed in the initial version of NCCDQOL on the Wright map (Fig. 2a). The WHOQOL-BREF performed like the NCCDQOL, but a more pronounced ceiling effect was observed in the SF-36, with 13 of the 36 items showing a ceiling effect (Fig. 2c). In addition, NCCDQOL and WHOQOL-BREF showed some ceiling effect in the Wright map, with only item-3 and item-2 (NCCDQOL) and Q2 (WHOQOL-BREF) having difficulty above the mean patient QOL score (Fig. 2a and d).

The Wright map of the initial version of NCCDQOL (Fig. 2a) revealed that the distribution of person scores followed a roughly normal distribution, but the distribution of items did not adequately cover the range of person abilities. The average line representing the abilities of the respondents (+0.75 logit) intersected with all items, and the most difficult item-3 (+0.80 logit) was below the average ability of the respondents (+1.06 logit). These findings suggest that, relative to the abilities of the respondents, the difficulty level of the items was too low. The mean item logit was 0±0.53, while the mean person logit was 1.06±1.09, indicating a difference of more than 1 logit between the means.

After item reduction in NCCDQOL, the Wright map (Fig. 2b) revealed that the four-category structure NCCDQOL evaluation resulted in self-reported QOL among patients who followed a normal distribution, and the difficulty levels of the items were fairly evenly distributed. The item with the highest difficulty was NCCD-9, while the item with the lowest difficulty was NCCD-4. However, the difficulty distribution of the items does not fully cover individuals' abilities, as some patients can easily obtain high scores on the most challenging items. We believe that the NCCDQOL demonstrates good construct validity. Although the discriminative ability for the highest QOL among NCCD patients is not ideal, this may be considered a necessary trade-off for the item scale. The revised NCCDQOL exhibits a superior structure compared to its initial version, showcasing improved reliability, discriminative ability, and a more balanced distribution of item difficulty.

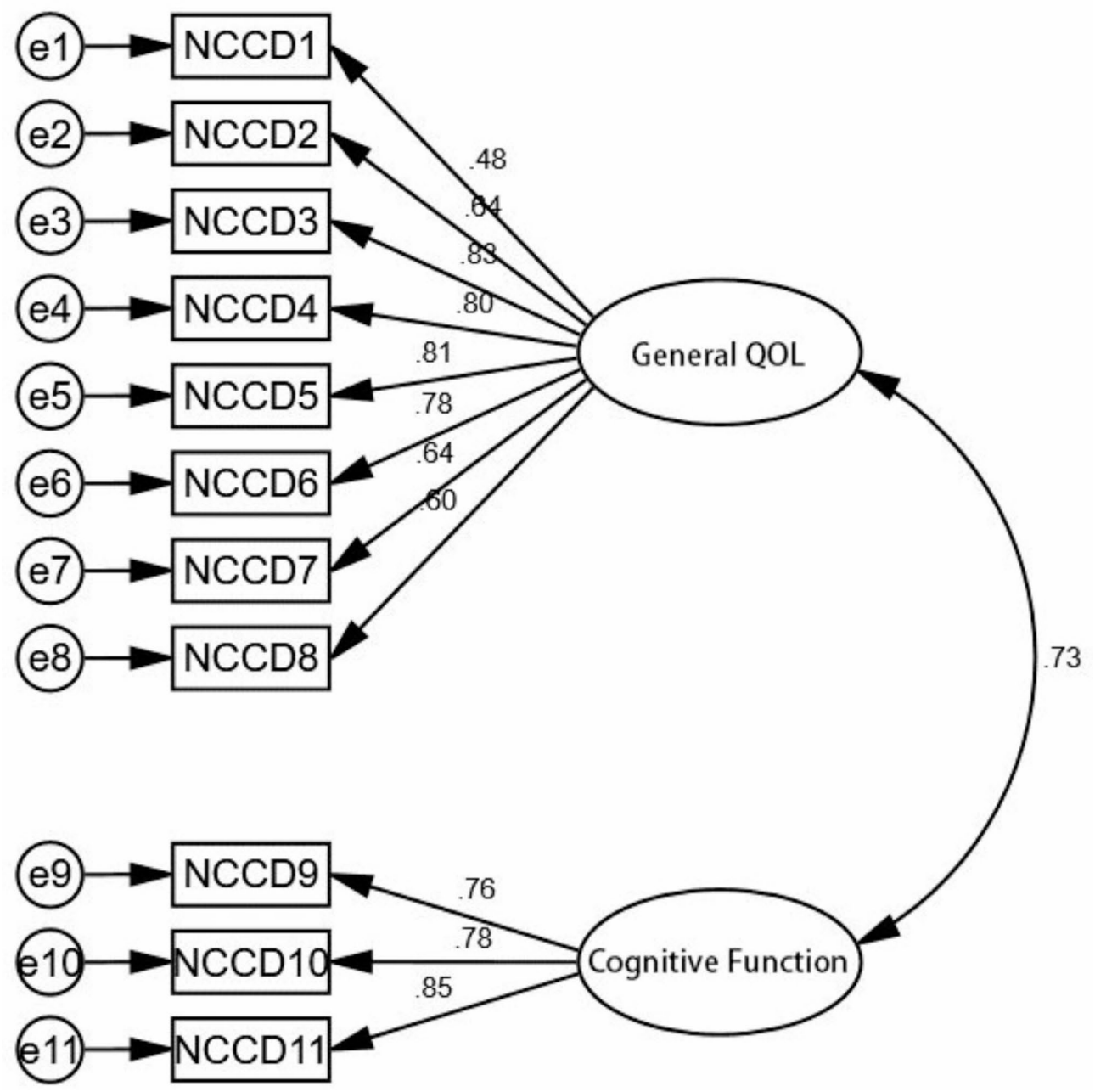

Fig. 7 CFA model fitting for NCCDQOL. Factor loadings between scales and domains are displayed above the arrows, with the exception of NCCD-1 (Global QOL) which exhibit lower loadings (< 0.5), while the rest fall within an acceptable range. Measurement errors and corresponding standardized residuals are shown on the left side

Table 8 Confirmatory factor fit indices

	χ2/df	GFI	AGFI	CFI	RMSEA
NCCDQOL	2.602	0.897	0.842	0.926	0.099
Criteria	< 5	> 0.80	> 0.80	> 0.90	< 0.10

Overall, the revised four-level scale, comprising 2 domains and 11 items, demonstrated good reliability and validity within the Rasch model. In our further study, we conducted a more comprehensive exploration of the effectiveness of SF-36 and WHOQOL-BREF among older individuals with NCCD, ultimately determining SF-36 to be the more appropriate scale [26]. Unlike these broad-scale measures, the NCCDQOL scale demonstrated superior specificity for the unique demographic of older individuals with NCCD. Moreover, its concise format, comprising just 11 items, alleviated survey burdens on patients and facilitated administration by healthcare professionals, rendering it ideal for swift and precise assessments within this population.

This study also has certain limitations. The data for this study are based on the EINCCDRCS, which imposes some limitations on the sample size of patients. Additionally, the validation of the revised Four-Category Structure NCCDQOL is currently ongoing in the EINCCDRCS. Therefore, we have not yet reported the results based on an independent validation set.

Conclusion

We have developed the NCCDQOL scale for evaluating the QOL in older individuals with NCCD based on existing scales primarily using the WHOQOL-OLD and tailored to the characteristics of older NCCD patients. The revised scale demonstrates good reliability and validity in the Rasch model and has promise for clinical applications. Further evaluation awaits the results of an independent set in our NCCD cohort and future large-scale clinical validation.

Abbreviations

CVD	Cardiovascular disease
NCDs	Noncommunicable Diseases
NCCD	Neuro-co-Cardiological Diseases
QOL	Quality of Life
WHOQOL	World Health Organization Quality of Life
SF-36	36-item Short Form
TIA	Transient Ischemic Attack
ECAS	Extracranial Carotid Artery Stenosis
ECAO	Extracranial carotid artery occlusion
ICAS	Intracranial carotid artery stenosis
ICAO	Intracranial carotid artery occlusion
IEMAS	Intracranial and extracranial multiple artery stenosis
IEMAO	Intracranial and extracranial multiple artery occlusion
CA	Cerebral aneurysm
MMD	Moyamoya disease
dAVFs	Dural arteriovenous fistula
CVST	Intracranial venous sinus thrombosis
CbVD	Cerebrovascular disease
AF	Atrial fibrillation
HF	Heart failure
MI	Myocardial infarction
WHOQOL-OLD	WHOQOL questionnaire for older adults
IQCODE	Informant Questionnaire on Cognitive Decline in the Elderly
EINCCDRCS	Elderly Individuals with Neuro-co-Cardiological Diseases Registered Cohort Study
DIF	Differential item functioning

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Author contributions

Conception and design: HZ, DS and DL. Analysis and interpretation of data: DS, DL and JY. Drafting the article: DS. Critically revising the article: WN, YC and CZ. Study supervision: HZ. All authors reviewed the manuscript.

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Data availability

The dataset supporting the conclusions of this article is included within the article's additional file.

Declarations

Ethics approval and informed consent

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of Sanbo Brain Hospital, Capital Medical University (Approval No. SBNK-YJ-2021-022-01). Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Competing interests

The authors have no relevant financial or non-financial interests to disclose.

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