

Patient-Reported Outcomes

Testing the Psychometric Properties of 9 Bolt-Ons for the EQ-5D-5L in a General Population Sample

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ABSTRACT

Objectives: We aimed to assess the psychometric performance and added value of 9 existing bolt-ons (breathing problems, cognition, hearing, self-confidence, skin irritation, sleep, social relationships, tiredness, and vision) for the EQ-5D-5L in a general population sample.

Methods: The EQ-5D-5L, 9 bolt-ons, SF-6Dv1, Patient-Reported Outcomes Measurement Information System (PROMIS)-29+2, PROMIS Global Health, and Satisfaction with Life Scale were completed in an online cross-sectional survey among a general adult population sample in Hungary (n = 1587). The following psychometric properties were tested for the EQ-5D-5L + bolt-on(s): ceiling, divergent and convergent validity, structural validity, known-group validity, and explanatory power.

Results: Adding sleep (30%), tiredness (24%), or vision (21%) substantially reduced the ceiling of the EQ-5D-5L (41%). Cognition, sleep, social relationships, and tiredness correlated with corresponding PROMIS and SF-6D items ($r_s = 10.321 - 10.731$). All bolt-ons, except cognition and self-confidence, loaded on a different factor from the EQ-5D-5L dimensions. Breathing, hearing, skin irritation, and vision significantly improved known-group validity in relevant health condition groups. The sleep bolt-on improved known-group validity in 9 of 13 chronic health conditions. Tiredness had the largest impact on explaining EQ VAS score variance in 8 of 13 conditions. Hearing and vision improved the ability of the EQ-5D-5L to capture declining health with age, whereas self-confidence and social relationships were valuable for mental health assessment.

Conclusions: This study established the validity of multiple bolt-ons for the EQ-5D-5L and highlights the usefulness of including relevant bolt-ons in population-based and patient surveys. Our findings inform the further development of these bolt-ons and the bolt-on item selection for clinical studies.

Keywords: bolt-on, EQ-5D-5L, health-related quality of life, psychometrics.

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Highlights

- Bolt-ons are additional dimensions that can be attached to the EQ-5D to capture aspects of health-related quality of life not sufficiently covered by the 5 core dimensions. Over the past 3 decades, numerous bolt-ons have been proposed for the EQ-5D. There is a need for high-quality psychometric evidence regarding bolt-ons to determine their added value.

- We provide a comprehensive analysis of the psychometric performance of 9 existing EQ-5D-5L bolt-ons (breathing problems, cognition, hearing, self-confidence, skin irritation, sleep, social relationships, tiredness, and vision) in a general population sample. The inclusion of bolt-ons led to a reduced ceiling and improved discriminatory power of the EQ-5D-5L across prevalent chronic health conditions (eg, cardiovascular diseases, depression, diabetes), age, and self-perceived health status groups.

- Relevant bolt-ons, offering a more comprehensive assessment of health-related quality of life, may be useful both in population-based studies and patient surveys. Our findings serve as a guide for selecting suitable bolt-ons in clinical studies and inform decisions for future instrument development endeavors, also beyond the EQ-5D.

Introduction

Generic preference-accompanied health-related quality of life (HRQoL) measures are recommended for obtaining quality-adjusted life-year estimates in economic evaluations by health technology assessment (HTA) bodies and guidelines in multiple countries.¹⁻⁴ However, depending on the specific instrument, content validity and responsiveness to change may be suboptimal in some areas, where an instrument lacks relevant dimensions.⁵⁻⁷ To address this limitation, additional dimensions (“bolt-ons”) relevant to specific conditions, health interventions, or contexts may be added to these instruments that supplement their core dimensions.⁸ Although the approach can theoretically be adopted to any HRQoL measure, bolt-ons have mainly been proposed for the EQ-5D.^{9,10} Two main reasons support this: first, the EQ-5D often exhibits a relatively high ceiling in many populations, possibly indicating less sensitivity in capturing milder HRQoL impairment.⁵ Another potential argument for the increased value

of bolt-ons, compared with other preference-accompanied measures, is rooted in the brevity of the EQ-5D. It includes only 5 items, in contrast to almost all other instruments, including the 12-item Short Form Health Survey, Patient-Reported Outcomes Measurement Information System-Preference, 15D, and Assessment of Quality of Life, which have more than 10 items.⁵ These longer questionnaires may include HRQoL areas such as sensory problems, vitality/fatigue, sleep, or cognitive problems that are not covered by the EQ-5D.

Bolt-on development has primarily focused on 4 areas for extending the EQ-5D’s descriptive system: (1) specific conditions or symptoms (eg, breathing problems, skin irritation),^{11,12} (2)

general HRQoL areas (eg, hearing, sleep, social relationships, vision, vitality),^{13,14} (3) well-being aspects (eg, dignity and happiness),¹⁵ and (4) HRQoL areas particularly important for the population of a specific country or region (eg, culturally relevant bolt-on developments in China, Hong Kong, Malaysia, South Korea, and Thailand).¹⁶⁻²⁰ It is important to examine the psychometric performance of the EQ-5D + bolt-on(s) to determine the added value of bolt-ons and to inform decisions for future instrument development work. To date, no large general population surveys have been undertaken to provide comprehensive evidence on the psychometric properties of multiple bolt-ons following the EQ-5D-5L format. Several bolt-on dimensions are expected to be relevant across various populations, including the general population. Therefore, the objective of this study is to investigate the psychometric performance of the EQ-5D-5L and 9 existing bolt-ons (breathing problems, cognition, hearing, self-confidence, skin irritation, sleep, social relationships, tiredness, and vision) and to assess the incremental benefit of appending bolt-ons to the EQ-5D-5L in a general population sample, including individuals with prevalent chronic conditions and different age groups.

Methods

Data Collection and Study Population

In November 2020, an online cross-sectional survey was conducted among 1700 members of the adult general population in Hungary.²¹⁻²⁴ Study participants were aged 18 years or older, were able to read and understand the questions in Hungarian, and gave their informed consent before participating in the survey. The study was approved by the Research Ethics Committee of the Corvinus University of Budapest (no. KRH/343/2020). "Soft quotas" were used to achieve a representative sample in terms of age, gender, place of residence, and region. Respondents completed the Hungarian versions of the EQ-5D-5L,²⁵ bolt-ons,^{11,12,14,26-28} the Patient-Reported Outcomes Measurement Information System (PROMIS)-29+2 v2.1,²⁹ SF-36v1,³⁰ PROMIS Global Health v1.2,³¹ and Satisfaction with Life Scale (SWLS)³² in a fixed order. Other data collected included socio-demographic characteristics and physician-diagnosed chronic health conditions.

Outcome Measures

EQ-5D-5L and bolt-ons

The EQ-5D-5L generic preference-accompanied measure consists of 2 parts: a descriptive system and a vertical visual analogue scale (EQ VAS), with endpoints of 0 (the worst health you can imagine) and 100 (the best health you can imagine).²⁵ The descriptive system includes 5 dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression, each with a single-item 5-level severity scale. The responses for the 5 dimensions can be combined into a 5-digit string, where 11111 and 55555 represent the best and worst possible health profiles, respectively. Nine single-item EQ-5D-5L bolt-ons were used in this study that had been developed in previous research.^{11,12,14,26-28} The order of the 9 bolt-on items in the questionnaire was as follows: cognition, sleep, social relationships, breathing problems (hereafter breathing), hearing, tiredness, vision, skin irritation, and self-confidence. All bolt-ons followed the format of the EQ-5D-5L descriptive system with a recall period of "today" (Appendix Table 1 found at <https://doi.org/10.1016/j.jval.2024.03.2195>).

PROMIS-29+2

PROMIS-29+2 is 31-item generic preference-accompanied measure that encompasses 8 domains: physical function, anxiety, depression, fatigue, sleep disturbance, social roles and activities, pain interference, and cognitive function.²⁹ Most domains consist of 4 items with 5 response options varying across severity, difficulty, frequency, or global rating. However, the cognitive function domain includes only 2 items. In addition, the questionnaire evaluates pain intensity using a numeric rating scale ranging from 0 to 10.

SF-6D

Respondents completed the SF-36v1 generic health status measure.³⁰ The SF-6D is a generic preference-accompanied measure derived from 11 items of the SF-36.³³ It comprises 6 health dimensions, each represented by a single item: physical functioning, role limitations, social functioning, pain, mental health, and vitality. The dimensions have 4 to 6 severity levels.

PROMIS Global Health

PROMIS Global Health is a 10-item measure of generic health status.³¹ It consists of 4 general items (health, quality of life, physical health, and mental health), 1 physical function, 1 fatigue, 1 pain intensity (identical to PROMIS-29+2), 1 emotional distress, and 2 social health items. Each question offers 5 severity-, frequency-, or global rating-format response options, except for the pain scale.

SWLS

SWLS is a measure of one's life satisfaction, as a component of subjective well-being.³² It asks respondents to express their level of agreement on 5 items using a 7-point scale, ranging from 1 (strongly disagree) to 7 (strongly agree).

Statistical Analyses

There were no missing data, because skipping items was not allowed in the online survey. We identified inconsistencies in the data and consequently excluded 113 respondents, resulting in a final sample size of 1587. The details of the exclusion process are described elsewhere.²² First, each bolt-on was tested individually, and then selected combinations of bolt-ons (and in some cases all 9 bolt-ons together) were tested. Combinations of bolt-ons were selected in a stepwise manner, considering the performance of each individual bolt-on. The best-performing bolt-on by psychometric property was selected as the first choice, followed by the second best and so forth. *P* values were considered statistically significant if they were lower than .05. Statistical analyses were performed using Stata 14.0 (StataCorp. 2015, College Station, TX) and R 4.2.3 (R Core Team, 2023, Vienna, Austria).

Distributional characteristics

For each EQ-5D-5L and bolt-on item, we first examined the distribution of responses across the 5 levels in the total sample and among different age strata and chronic health condition groups to demonstrate that all levels are endorsed and have relevance. The proportion of respondents reporting the best (ceiling) and worst (floor) possible health in each bolt-on item was examined. The distribution of responses of participants in 11111 on the EQ-5D-5L was examined across the 9 bolt-on items. For each bolt-on or combinations of bolt-ons, the absolute and relative reduction in the ceiling were calculated as follows:

Absolute reduction in ceiling :

$$ceiling_{EQ-5D-5L} - ceiling_{EQ-5D-5L+bolt-on(s)}$$

Relative reduction in ceiling :

$$\frac{\text{ceiling}_{EQ-5D-5L} - \text{ceiling}_{EQ-5D-5L+bolt-on(s)}}{\text{ceiling}_{EQ-5D-5L}}$$

We calculated the number of different health profiles in the sample when adding bolt-on(s). The proportion of respondents indicating “any problems” across age groups was visualized, and the differences were tested using a chi-square test.

Divergent validity: correlations between EQ-5D-5L items and bolt-ons

Potential overlaps between the bolt-on and EQ-5D-5L items were analyzed using Spearman's correlations. Correlation coefficients were interpreted as very weak (<0.20), weak (0.20-0.39), moderate (0.40-0.59), and strong (≥ 0.60).³⁴ We expected a moderate correlation of (1) cognition and tiredness with usual activities; (2) skin irritation, sleep, and tiredness with pain/discomfort; and (3) cognition, self-confidence, sleep, social relationships, and tiredness with anxiety/depression.^{13,22,35-41} Otherwise, we hypothesized that each bolt-on item would demonstrate very weak or weak correlation with the 5 EQ-5D-5L items.

Comparison of bolt-ons with items of other instruments and convergent validity

We compared ceiling, floor, and convergent validity (Spearman's correlations) of each bolt-on item with corresponding SF-6D, PROMIS-29+2, and Global Health items and domains aiming to capture similar constructs. We hypothesized at least moderate correlations between these corresponding items or domains.

Structural validity

To investigate the structural validity of the EQ-5D-5L and the 9 bolt-ons, we used confirmatory factor analysis (CFA). The CFA was informed by 3 sources of evidence: (1) previous studies that identified bolt-ons for the EQ-5D-5L from items of other generic HRQoL and well-being measures using CFA,^{27,42} (2) content analysis of available items in our survey following the conceptual model proposed by Wilson and Cleary,⁴³ and (3) principal component analysis (PCA) conducted on the items in our survey.

In both the PCA and CFA, in addition to the EQ-5D-5L items and 9 bolt-ons, we included items from PROMIS-29+2, SF-6D, PROMIS Global Health, and SWLS to aid model identification and robustness. Due to the overlap in the pain intensity numeric rating scale between PROMIS-29+2 and Global Health, we included this item only once (that of the PROMIS-29+2), resulting in a pool of 65 items. All item responses were recoded so that a higher score indicated worse HRQoL or well-being. For the PCA, we used a promax rotation, and the number of factors was determined based on the Kaiser's criterion (ie, all factors with an eigenvalue > 1 were retained).⁴⁴ The CFA was conducted using the *lavaan* package in R.⁴⁵ The diagonally weighted least square estimator was used to compute factor loadings.⁴⁶ Model fit was considered acceptable when (1) the root mean square error of approximation <0.08 and comparative fit index >0.95, (2) modification indices <100, (3) factor loadings >0.32, and (4) residual correlations <|0.2|. ⁴⁷⁻⁴⁹ However, all but the first criterion were considered less strictly and they were rather treated in comparison with other items in the scale and not in isolation.⁵⁰ To ease interpretation, factor loadings were standardized to a range between 0 and 1. Gradual adjustments were made to the model, including the omission of items with low factor loadings and allowing local dependence

between certain items. Both for PCA and CFA, factor loadings were interpreted according to the following benchmark values: ≤ 0.32 (unacceptable), 0.33 to 0.44 (poor), 0.45 to 0.54 (fair), 0.55 to 0.62 (good), 0.63 to 0.70 (very good), and ≥ 0.71 (excellent).⁴⁷

The final CFA model was used to classify bolt-ons into 2 groups: (1) bolt-ons that do not cover a similar construct as any EQ-5D-5L items (ie, they load on different factors) and (2) bolt-ons that cover a partially overlapping construct (ie, they load on the same factors) with any EQ-5D-5L items. Loading on a different factor signals a stronger argument to support that the bolt-on captures a construct that the core instrument cannot fully address.

Known-group validity

To assess known-group validity of the EQ-5D-5L with bolt-on(s) compared with the EQ-5D-5L, mean level sum scores (LSSs) were computed and transformed to a 0 to 100 scale to ensure comparability of scores with and without bolt-ons. Previous research has shown the relatively robust psychometric properties of LSSs, making them a useful outcome for exploratory methodological research.^{51,52} We hypothesized that bolt-ons improve the ability of the EQ-5D-5L to distinguish between known groups, which were defined by healthy respondents versus those with health conditions, age strata, and health and quality of life (first 4 questions of PROMIS Global Health), and well-being (SWLS) subgroups. The relative efficiency in detecting differences between known groups was computed as the ratio of the F-statistic used in the analysis of variance.⁵¹ We used EQ-5D-5L as a reference to determine relative efficiency; thus, an F-ratio >1 indicated that EQ-5D-5L + bolt-on was more efficient in differentiating across (sub)groups. To test whether an F-ratio was significantly different from 1, we estimated 95% CIs using 3000 bootstrap replications. Additional bolt-ons were attached to the EQ-5D-5L until the EQ-5D-5L + *n* bolt-on(s) resulted in a statistically significant increase in relative efficiency compared with EQ-5D-5L + *n-1* bolt-on(s). Both for known-group validity and explanatory power analyses, the selection of potentially relevant bolt-ons was based on the literature and expert opinion of the authors (Appendix Table 2 found at <https://doi.org/10.1016/j.jval.2024.03.2195>).

Explanatory power

Linear regressions were used to explore whether the different bolt-ons or combinations of bolt-ons contribute to explain the variance in HRQoL or subjective well-being. Three different model versions were tested, each with a different dependent variable: EQ VAS, PROMIS Global Health raw sum score (calculated by summing the responses of the 10 items), and SWLS score. Initially, each item was examined in univariable models, followed by multivariable models that included the 5 EQ-5D-5L items and combinations of bolt-on items. For the latter, bolt-on items were included consecutively until no further increase in adjusted R² was generated by adding one more item. Considering that different bolt-ons may be relevant for specific chronic health condition groups, the analysis was repeated for these subgroups.

Results

Distributional Characteristics

The characteristics of the study sample were comparable with the Hungarian national population (Appendix Table 2 found at <https://doi.org/10.1016/j.jval.2024.03.2195>). A total of 203 different health profiles (7% of all possible profiles) occurred on the EQ-5D-5L, which increased with the addition of even 1 bolt-on

Table 1. Ceiling and number of health state profiles on EQ-5D-5L and bolt-ons.

Dimensions	Ceiling		Ceiling (EQ-5D-5L + bolt-on [s])		Absolute ceiling reduction (%)	Relative ceiling reduction (%)	Number of health state profiles			
	n	%	n	%			n	%	max	20 most frequent profiles (%)
MO	1117	70.4			-	-				
SC	1471	92.7			-	-				
UA	1249	78.7	643	40.5	-	-	203	6.5	3125	79.3
PD	894	56.3			-	-				
AD	1055	66.5			-	-				
VI	654	41.2	329	20.7	19.8	48.8	317	2.0	15 625	67.4
TI	603	38.0	388	24.4	16.1	39.7	319	2.0	15 625	68.0
SL	876	55.2	474	29.9	10.6	26.3	324	2.1	15 625	67.8
SE	907	57.2	478	30.1	10.4	25.7	310	2.0	15 625	68.5
HE	1247	78.6	550	34.7	5.9	14.5	292	1.9	15 625	71.3
SR	1144	72.1	561	35.3	5.2	12.8	310	2.0	15 625	70.4
SI	1279	80.6	571	36.0	4.5	11.2	286	1.8	15 625	71.5
BR	1280	80.7	599	37.7	2.8	6.8	293	1.9	15 625	71.6
CO	1275	80.3	611	38.5	2.0	5.0	282	1.8	15 625	73.5
VI + TI	315	19.8	218	13.7	26.8	66.1	447	0.6	78 125	53.8
VI + SL + TI	261	16.4	193	12.2	28.4	70.0	597	0.2	390 625	43.7
VI + SE + SL + TI	230	14.5	176	11.1	29.4	72.6	755	0.0	1 953 125	36.5
VI + HE + SE + SR + TI	215	13.5	165	10.4	30.1	74.3	838	0.0	9 765 625	32.5
All 9 bolt-ons	193	12.2	151	9.5	31.0	76.5	1049	0.0	6 103 515 625	26.1

AD indicates anxiety/depression; BR, breathing problems; CO, cognition; HE, hearing; max, maximum; MO, mobility; PD, pain/discomfort; SC, self-care; SE, self-confidence; SI, skin irritation; SL, sleep; SR, social relationships; TI, tiredness; UA, usual activities; VI, vision.

(Table 1). The 20 most common profiles accounted for 79.3% of the sample, and this percentage gradually decreased with the inclusion of additional bolt-ons in the descriptive system.

The ceiling for bolt-ons varied from 38% (tiredness) and 81% (breathing) (Table 1). Three bolt-on items (sleep, tiredness, and vision) exhibited a lower ceiling than any EQ-5D-5L items. The floor was very small (<2%) for all bolt-on items. The distribution of responses showed a great variability across chronic health condition groups (Appendix Table 3 found at <https://doi.org/10.1016/j.jval.2024.03.2195>). Health problems on the breathing, hearing, skin irritation, sleep, and vision problems demonstrated an upward trend with age, whereas self-confidence and social relationships decreased ($P < .05$) (Fig. 1). Cognition showed a mild U-shaped curve, whereas no clear trend was observed for tiredness.

The ceiling of the EQ-5D-5L was 41%. Overall, 77% of those who responded 11111 on the EQ-5D-5L reported problems on at least 1 bolt-on item (Fig. 1). The addition of any bolt-on to the EQ-5D-5L yielded a reduction in the ceiling (Table 1). The greatest reduction was observed with the vision (21%), tiredness (24%), sleep (30%), and self-confidence (30%) bolt-ons. The reduction in ceiling increased with the number of bolt-on items; however, the additional reduction was marginal after adding the second bolt-on.

Divergent Validity: Correlations Between EQ-5D-5L Items and Bolt-Ons

Bolt-on items exhibited correlations of varying strength with EQ-5D-5L items (Table 2). Corroborating our hypotheses,

breathing, hearing, and vision bolt-ons were only weakly correlated with any of the EQ-5D-5L items. As opposed to our expectations, there was only a weak correlation between skin irritation and pain/discomfort. Tiredness demonstrated moderate correlations with both pain/discomfort and anxiety/depression. The cognition, self-confidence, and social relationships bolt-ons showed moderate correlations with anxiety/depression.

Comparison of Bolt-Ons With Items of Other Instruments and Convergent Validity

In most comparable cases, the bolt-on items showed a higher ceiling and lower floor than the corresponding items of other instruments (Appendix Table 4 found at <https://doi.org/10.1016/j.jval.2024.03.2195>). The self-confidence, sleep, and tiredness bolt-ons demonstrated a moderate or strong correlation with their PROMIS and SF-6D item/domain pairs, whereas correlations were generally weak or moderate for cognition and social relationships.

Structural Validity

The PCA identified 10 factors using the Kaiser's criterion, explaining 71% of the total variance (Appendix Table 5 found at <https://doi.org/10.1016/j.jval.2024.03.2195>). In the initial CFA model, the cognition bolt-on was associated with psychological functioning instead of a separate cognitive function factor. This led to the omission of the cognitive function domain of PROMIS-29+2 given that no other items were loaded on the same factor, and 2-item scales are not considered useful. The final CFA model

Figure 1. EQ-5D-5L and bolt-on response distribution and respondents with any problems by dimension and age group.

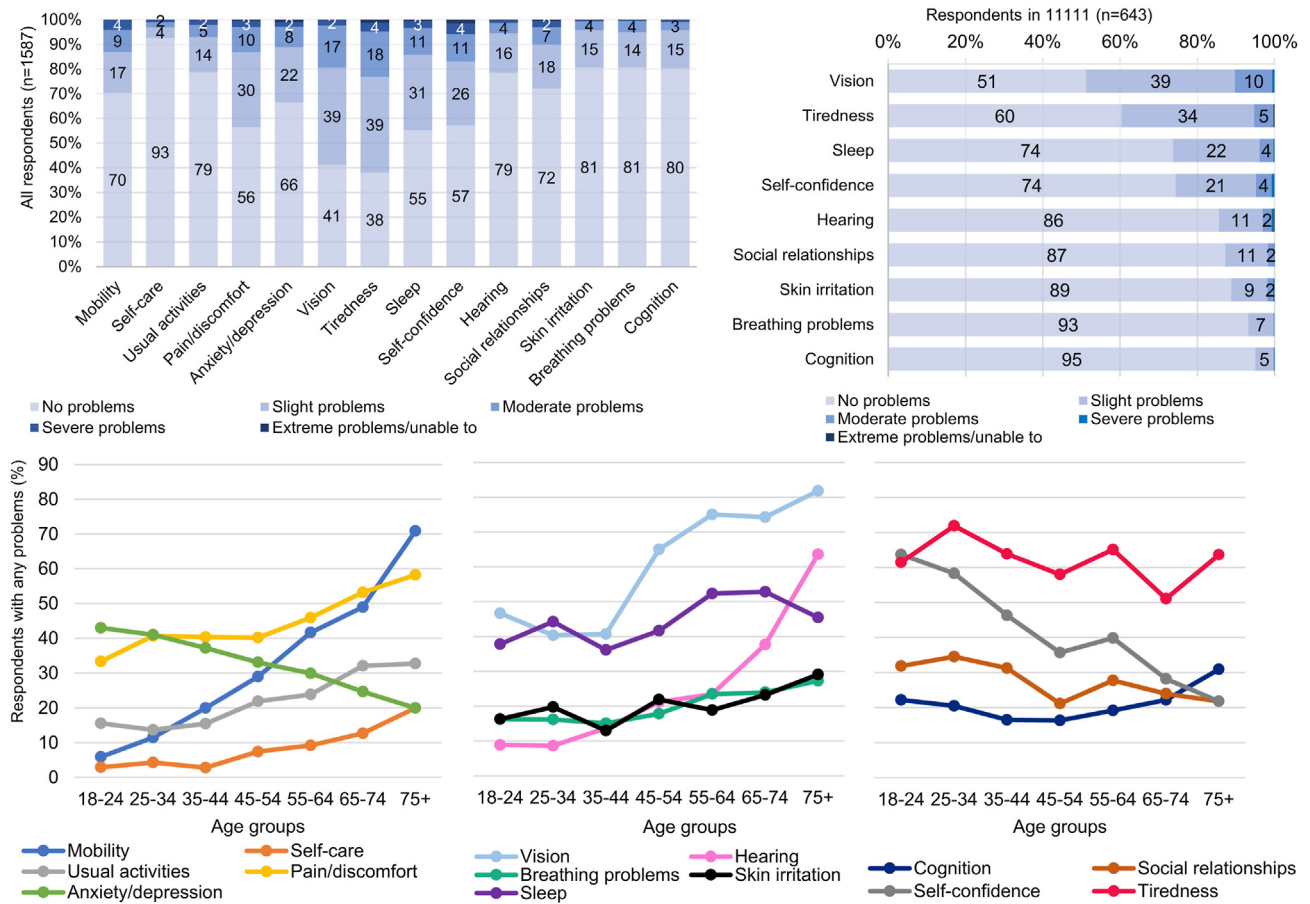


Table 2. Spearman’s correlation coefficients between EQ-5D-5L, bolt-ons, and EQ VAS.

Variables	EQ-5D-5L					Bolt-ons									
	MO	SC	UA	PD	AD	VI	TI	SL	SE	HE	SR	SI	BR	CO	
MO	-														
SC	0.44	-													
UA	0.52	0.49	-												
PD	0.52	0.37	0.54	-											
AD	0.21	0.20	0.34	0.45	-										
VI	0.27	0.20	0.26	0.22	0.21	-									
TI	0.28	0.23	0.35	0.47	0.50	0.25	-								
SL	0.26	0.18	0.26	0.36	0.38	0.27	0.41	-							
SE	0.07	0.11	0.24	0.27	0.55	0.21	0.45	0.31	-						
HE	0.26	0.25	0.22	0.19	0.09	0.30	0.14	0.21	0.07	-					
SR	0.13	0.19	0.26	0.30	0.47	0.22	0.35	0.31	0.49	0.13	-				
SI	0.15	0.17	0.21	0.20	0.19	0.21	0.22	0.19	0.20	0.19	0.18	-			
BR	0.25	0.21	0.26	0.32	0.25	0.27	0.31	0.28	0.18	0.22	0.23	0.16	-		
CO	0.27	0.29	0.36	0.36	0.45	0.27	0.37	0.29	0.36	0.21	0.39	0.18	0.23	-	
EQ VAS	-0.44	-0.31	-0.45	-0.56	-0.41	-0.27	-0.44	-0.34	-0.30	-0.21	-0.30	-0.18	-0.33	-0.35	

Note. All correlation coefficients are significant ($P < .01$). AD indicates anxiety/depression; BR, breathing problems; CO, cognition; EQ VAS, EuroQol visual analogue scale; HE, hearing; MO, mobility; PD, pain/discomfort; SC, self-care; SE, self-confidence; SI, skin irritation; SL, sleep; SR, social relationships; TI, tiredness; UA, usual activities; VI, vision.

Table 3. Results of the multidimensional confirmatory factor analysis (standardized factor loadings).

Energy/fatigue		Psychological functioning	
EQ-5D-5L Tiredness bolt-on	0.852	EQ-5D-5L Anxiety/depression	0.899
PROMIS-29+2 Fatigued	0.909	EQ-5D-5L Self-confidence bolt-on	0.768
PROMIS-29+2 Trouble starting things	0.928	EQ-5D-5L Cognition bolt-on (memory, comprehension, concentration, thinking)	0.792
PROMIS-29+2 Run-down	0.919	PROMIS-29+2 Fearful	0.870
PROMIS-29+2 Fatigued on average	0.940	PROMIS-29+2 Hard to focus on anything other than anxiety	0.907
PROMIS-29+2 Refreshing sleep	0.707	PROMIS-29+2 Overwhelming worries	0.873
PROMIS Global08 (fatigue)	0.881	PROMIS-29+2 Uneasy	0.880
SF-6D Vitality (energy)	0.789	PROMIS-29+2 Worthless	0.874
General health		PROMIS-29+2 Helpless	0.888
PROMIS Global01 (health)	0.961	PROMIS-29+2 Depressed	0.927
PROMIS Global02 (quality of life)	0.868	PROMIS-29+2 Hopeless	0.941
PROMIS Global03 (physical health)	0.955	PROMIS Global10 (emotional problems, such as anxious, depressed, irritable)	0.881
PROMIS Global04 (mental health, incl. mood and ability to think)	0.941	SF-6D Mental health (tense or downhearted)	0.790
Pain		Satisfaction	
EQ-5D-5L Pain/discomfort	0.874	SWLS Life close to ideal	0.910
PROMIS-29+2 Pain interference with day to day activities	0.966	SWLS Excellent life conditions	0.912
PROMIS-29+2 Pain interference with work around the home	0.969	SWLS Satisfied with one's life	0.954
PROMIS-29+2 Pain interference with household chores	0.950	SWLS Gotten the important things wanted	0.830
PROMIS-29+2 Pain interference with social activities	0.971	SWLS If started over, would change almost nothing	0.698
PROMIS-29+2 Pain intensity 0-10	0.811	Sleep	
SF-6D Pain	0.871	EQ-5D-5L Sleep bolt-on	0.930
Physical functioning		PROMIS-29+2 Sleep quality	0.830
EQ-5D-5L Mobility (walking)	0.803	PROMIS-29+2 Problem with sleep	0.747
EQ-5D-5L Self-care (washing or dressing)	0.885	PROMIS-29+2 Difficulty falling asleep	0.873
EQ-5D-5L Usual activities (work, study, housework, family or leisure activities)	0.884	Social functioning	
PROMIS-29+2 Vacuuming and yard work	0.927	EQ-5D-5L Social relationships bolt-on	0.723
PROMIS-29+2 Going up and down stairs at a normal pace	0.892	PROMIS-29+2 Doing family activities	0.884
PROMIS-29+2 Going for a walk of at least 15 minutes	0.916	PROMIS-29+2 Doing activities with friends	0.894
PROMIS-29+2 Run errands and shop	0.924	PROMIS-29+2 Doing regular leisure activities with others	0.897
PROMIS Global06 (physical activities, such as walking, climbing stairs, carrying groceries or moving a chair)	0.922	PROMIS-29+2 Doing usual work (include work at home)	0.909
SF-6D Physical functioning (vigorous activities, moderate activities, bathing and dressing)	0.856	PROMIS Global05 (satisfaction with social relationships and activities)	0.740
SF-6D Role limitations (work or other daily activities)	0.826	PROMIS Global09 (social activities and roles, incl. at home, work, your community, responsibilities as parent, child, spouse, employee, friend)	0.789
Physical symptoms (other)		SF-6D Social functioning (limitations in social activities)	0.754
EQ-5D-5L Vision bolt-on	0.599		
EQ-5D-5L Hearing bolt-on	0.477		
EQ-5D-5L Skin irritation bolt-on (itching)	0.540		
EQ-5D-5L Breathing bolt-on (shortness of breath, wheezing, coughing, sputum)	0.797		

PROMIS indicates Patient-Reported Outcomes Measurement Information System; SF-6D, Short Form 6 Dimension; SWLS, Satisfaction with Life Scale.

Table 4. Known-group validity of EQ-5D-5L (plus bolt-ons) across 13 health condition groups.

EQ-5D-5L + selected bolt-ons	EQ-5D-5L (+ bolt-on ceiling (%))		EQ-5D-5L (+ bolt-on mean (SD) LSS		RE (95% CI), ref: previous row	RE (95% CI), ref: no bolt-ons
	Healthy (n = 388)	Chronic condition	Healthy (n = 388)	Chronic condition		
Allergies (n = 277)						
EQ-5D-5L	70.9	28.5	3.1 (7.8)	12.5 (14.2)	-	-
EQ-5D-5L + SL	58.2	20.2	3.7 (7.5)	13.9 (13.8)	1.24 (1.12-1.40)	
EQ-5D-5L + SL + TI	42.3	9.7	5.2 (8.0)	16.2 (13.9)	1.13 (1.02-1.24)	
EQ-5D-5L + SI + SL + TI	40.7	7.9	4.9 (7.4)	15.6 (13.1)	1.09 (1.03-1.16)	1.53 (1.30-1.84)
Anxiety (n = 160)						
EQ-5D-5L	70.9	1.9	3.1 (7.8)	26.5 (18.6)	-	-
EQ-5D-5L + SL	58.2	0.6	3.7 (7.5)	27.9 (17.6)	1.18 (1.09-1.28)	
EQ-5D-5L + SL + TI	42.3	0.6	5.2 (8.0)	30.3 (17.2)	1.07 (1.01-1.15)	1.26 (1.21-1.41)
Cardiovascular diseases (n = 218)						
EQ-5D-5L	70.9	16.5	3.1 (7.8)	20.6 (19.1)	-	-
EQ-5D-5L + SL	58.2	9.6	3.7 (7.5)	21.4 (18.3)	1.11 (1.03-1.19)	
EQ-5D-5L + BR + SL	46.9	7.8	4.4 (7.5)	20.4 (17.1)	1.06 (1.01-1.11)	1.18 (1.09-1.28)
Depression (n = 120)						
EQ-5D-5L	70.9	1.7	3.1 (7.8)	29.5 (19.1)	-	-
EQ-5D-5L + SL	58.2	0	3.7 (7.5)	31.0 (17.9)	1.19 (1.10-1.31)	1.19 (1.1-1.31)
Diabetes (n = 173)						
EQ-5D-5L	70.9	26	3.1 (7.8)	16.4 (18.1)	-	-
EQ-5D-5L + VI	46.9	6.9	4.3 (7.5)	18.1 (16.6)	1.26 (1.14-1.40)	
EQ-5D-5L + SL + VI	40.2	5.8	4.7 (7.2)	18.5 (16.2)	1.21 (1.12-1.33)	1.33 (1.18-1.54)
Eye or visual disorders (n = 267)						
EQ-5D-5L	70.9	19.9	3.1 (7.8)	17.9 (17.9)	-	-
EQ-5D-5L + VI	46.9	1.5	4.3 (7.5)	21.3 (16.0)	1.58 (1.45-1.75)	1.58 (1.45-1.75)
GERD, gastric/peptic ulcer (n = 180)						
EQ-5D-5L	70.9	17.8	3.1 (7.8)	18.4 (15.8)	-	-
EQ-5D-5L + SL	58.2	11.7	3.7 (7.5)	20.2 (15.3)	1.25 (1.14-1.38)	1.25 (1.14-1.38)
Headache, migraine (n = 130)						
EQ-5D-5L	70.9	11.5	3.1 (7.8)	21.8 (19.2)	-	-
EQ-5D-5L + TI	47.9	5.4	4.9 (8.2)	25.1 (18.3)	1.19 (1.08-1.32)	
EQ-5D-5L + SL + TI	42.3	4.6	5.2 (8.0)	26.2 (18.3)	1.10 (1.02-1.19)	1.31 (1.14-1.51)
Hearing problems (n = 93)						
EQ-5D-5L	70.9	17.2	3.1 (7.8)	19.8 (20.3)	-	-
EQ-5D-5L + HE	65.2	1.1	3.0 (7.0)	23.6 (17.6)	1.95 (1.68-2.41)	1.95 (1.68-2.41)
Hypertension (n = 466)						
EQ-5D-5L	70.9	24.2	3.1 (7.8)	15.9 (17.2)	-	-
EQ-5D-5L + SL	58.2	15.2	3.7 (7.5)	16.9 (16.4)	1.16 (1.08-1.25)	
EQ-5D-5L + BR + SL	46.9	12.7	4.4 (7.5)	15.8 (15.2)	1.05 (1.01-1.09)	1.22 (1.12-1.32)
Musculoskeletal diseases (n = 481)						
EQ-5D-5L	70.9	14.8	3.1 (7.8)	18.6 (16.3)	-	-
EQ-5D-5L + SL	58.2	7.9	3.7 (7.5)	19.3 (15.6)	1.09 (1.03-1.17)	1.09 (1.03-1.17)
Respiratory diseases (n = 141)						
EQ-5D-5L	70.9	17.7	3.1 (7.8)	17.1 (17.0)	-	-
EQ-5D-5L + BR	68.8	9.9	2.9 (7.0)	18.4 (15.9)	1.44 (1.30-1.62)	1.44 (1.30-1.62)

continued on next page

Table 4. Continued

EQ-5D-5L + selected bolt-ons	EQ-5D-5L (+ bolt-on) ceiling (%)		EQ-5D-5L (+ bolt-on) mean (SD) LSS		RE (95% CI), ref: previous row	RE (95% CI), ref: no bolt-ons
	Healthy (n = 388)	Chronic condition	Healthy (n = 388)	Chronic condition		
Skin diseases (n = 120)						
EQ-5D-5L	70.9	27.5	3.1 (7.8)	15 (16.6)	-	-
EQ-5D-5L + SI	66.8	13.3	3.0 (7.0)	15.7 (14.9)	1.41 (1.24-1.65)	1.41 (1.24-1.65)

Note. In diseases where more than 1 bolt-on improved the relative efficiency of the EQ-5D-5L, we computed 2 relative efficiency values. One compared the EQ-5D-5L + n bolt-on(s) with the EQ-5D-5L + n-1 bolt-on(s), and the other compared the EQ-5D-5L + n bolt-on(s) with the EQ-5D-5L alone. BR indicates breathing; GERD, gastroesophageal reflux disease; HE, hearing; LSS, level sum score; RE, relative efficiency; SE, self-confidence; SI, skin irritation; SL, sleep; TI, tiredness; Vi, vision.

demonstrated an appropriate fit to the data with an root mean square error of approximation of 0.076 (95% CI 0.075-0.077) and comparative fit index of 0.991. In this model, 63 items were loaded on the following 9 factors: psychological functioning, physical functioning, pain, energy/fatigue, satisfaction, general health, sleep, social functioning, and other physical symptoms (Table 3). All items except hearing and skin irritation had a standardized factor loading ≥ 0.55 , suggesting a good fit. Seven of the 9 bolt-ons loaded on a different factor than any of the EQ-5D-5L items: “energy/fatigue” (tiredness), “sleep” (sleep), “social functioning” (social relationships), and “other physical symptoms” (breathing, hearing, skin irritation, and vision). The cognition and self-confidence bolt-ons loaded on the same “psychological functioning” factor as the anxiety/depression item.

Known-Group Validity

We observed substantial variations in the mean LSS change when adding different bolt-on items to the EQ-5D-5L (Table 4 and Appendix Table 6 found at <https://doi.org/10.1016/j.jval.2024.03.2195>). As expected, the inclusion of (combinations of) bolt-ons significantly improved the instrument’s ability to detect differences between respondents with chronic conditions and healthy respondents, with relative efficiencies ranging from 1.09 (95% CI 1.03-1.17) to 1.95 (95% CI 1.68-2.41). Examples of conditions include eye and visual disorders (vision), hearing impairment (hearing), respiratory diseases (breathing), skin diseases (skin irritation), depression (sleep), headache/migraine (sleep and tiredness), and cardiovascular diseases (breathing and sleep). The hearing and vision bolt-ons were particularly effective in capturing declining health with age. The vision or the vision and tiredness bolt-ons improved the relative efficiency for assessing health status, physical health, and quality of life, whereas cognition, self-confidence, social relationships, and tiredness were better in differentiating between groups based on mental health and well-being.

Explanatory Power

In univariable regressions for EQ VAS, the adjusted R^2 was the highest for tiredness and the smallest for skin irritation (Table 5). Regarding PROMIS Global Health, the highest adjusted R^2 was achieved by the tiredness bolt-on, whereas the lowest was observed with hearing. Corresponding bolt-ons for SWLS score were social relationships and hearing. In multivariable regressions including the 5 EQ-5D-5L items, the adjusted R^2 values were 0.44, 0.52, and 0.24 for the EQ VAS, PROMIS Global Health, and SWLS, respectively. The increase in adjusted R^2 was modest, irrespective of the primary construct used as a dependent variable or the

chronic condition group (Appendix Table 7 found at <https://doi.org/10.1016/j.jval.2024.03.2195>).

Discussion

This study performed a comprehensive and large-scale examination of the psychometric properties of 9 existing bolt-ons for the EQ-5D-5L in a representative sample of the Hungarian adult general population. We relied on multiple methods to test a wide range of psychometric properties and to determine the value of adding bolt-ons to the EQ-5D-5L. Strong psychometric evidence was found for some bolt-ons at item level (eg, self-confidence, sleep, tiredness, vision) and in enhancing the performance of the EQ-5D-5L instrument as a whole (eg, breathing, hearing, self-confidence, skin irritation, vision). Our study adds to the growing body of bolt-on literature in several ways. First, given that the 9 bolt-ons examined in this study are still in developmental phase, the results can contribute to shaping their further development. Second, this study provides an example framework for conducting a comprehensive assessment of the psychometric properties of multiple bolt-ons. Third, the specific findings have relevance not only for future general population surveys but also for guiding the selection of appropriate bolt-ons for various patient populations.

In line with previous research,⁵³⁻⁵⁵ the 2 sensory bolt-ons, hearing and vision, significantly improved the ability of the EQ-5D-5L to detect differences in HRQoL among patients with hearing impairments and eye and visual disorders, respectively. Breathing and skin irritation also demonstrated good known-group validity in relevant disease groups (breathing, respiratory and cardiovascular diseases; skin irritation, skin diseases and allergies) confirming the findings of earlier work in patients with chronic obstructive pulmonary disease, burns, and psoriasis.^{11,12,56,57} The sleep bolt-on performed exceptionally well in known-group validity analyses and made the greatest contribution to improving the EQ-5D-5L’s performance in 9 of 13 chronic health conditions, including both physical and mental illnesses. In contrast, tiredness contributed the most to explaining the variance in EQ VAS scores in 8 of 13 conditions. The cognition bolt-on used in this study did not meet our expectations in terms of psychometrics. These findings suggest that although cognition is an important element of HRQoL also for the general population, it may be more effectively captured by using alternatively worded or separate items targeting different subdomains of cognition.

Little is known about the maximum number of bolt-ons that can be attached to the EQ-5D and how to determine the optimal balance between the number of items and their added value in

Table 5. Uni- and multivariable regressions on EQ VAS, PROMIS Global Health total score and SWLS.

Selection of dimensions	EQ VAS		PROMIS Global Health total score (raw)		SWLS	
	Adjusted R ²	ΣΔ adjusted R ²	Adjusted R ²	ΣΔ adjusted R ²	Adjusted R ²	ΣΔ adjusted R ²
EQ-5D-5L dimensions						
MO	0.2343	-	0.2495	-	0.0777	-
SC	0.1528	-	0.1407	-	0.0504	-
UA	0.2555	-	0.2689	-	0.1029	-
PD	0.3639	-	0.4079	-	0.1563	-
AD	0.2053	-	0.3080	-	0.1859	-
Bolt-on dimensions						
VI	0.0902	-	0.1271	-	0.0607	-
TI	0.2194	-	0.3298	-	0.1298	-
SL	0.1604	-	0.2043	-	0.1050	-
SE	0.0920	-	0.2057	-	0.1626	-
HE	0.0519	-	0.0542	-	0.0158	-
SR	0.1183	-	0.2047	-	0.1648	-
SI	0.0301	-	0.0595	-	0.0325	-
BR	0.1280	-	0.1442	-	0.0750	-
CO	0.1626	-	0.2063	-	0.1050	-
EQ-5D-5L (+ bolt-on dimensions)						
EQ-5D-5L	0.4404	-	0.5234	-	0.2373	-
EQ-5D-5L + SR	-	-	-	-	0.2700	0.0327
EQ-5D-5L + TI	0.4550	0.0146	0.5602	0.0368	-	-
EQ-5D-5L + SE + SR	-	-	-	-	0.2879	0.0506
EQ-5D-5L + SE + TI	-	-	0.5754	0.0520	-	-
EQ-5D-5L + SL + TI	0.4618	0.0214	-	-	-	-
EQ-5D-5L + SE + SR + TI	-	-	0.5808	0.0574	0.2888	0.0515
EQ-5D-5L + BR + SL + TI	0.4671	0.0267	-	-	-	-
EQ-5D-5L + SE + SL + SR + TI	-	-	0.5846	0.0612	-	-
EQ-5D-5L + BR + SL + TI + VI	0.4687	0.0283	-	-	-	-
EQ-5D-5L + SE + SL + SR + TI + VI	-	-	0.5893	0.0659	-	-
EQ-5D-5L + BR + CO + SL + TI + VI	0.4701	0.0297	-	-	-	-
EQ-5D-5L + BR + SE + SL + SR + TI + VI	-	-	0.5912	0.0678	-	-
EQ-5D-5L + BR + CO + SL + SR + TI + VI	0.4702	0.0298	-	-	-	-
EQ-5D-5L + BR + CO + HE + SL + SR + TI + VI	0.4703	0.0299	-	-	-	-

AD indicates anxiety/depression; BR, breathing problems; CO, cognition; EQ VAS, EuroQol visual analogue scale; HE, hearing; SC, self-care; SE, self-confidence; SL, sleep; SI, skin irritation; SR, social relationships; MO, mobility; PD, pain/discomfort; PROMIS, Patient-Reported Outcomes Measurement Information System; SWLS, Satisfaction With Life Scale; TI, tiredness; UA, usual activities; VI, vision.

terms of improved psychometrics. The existing literature suggests that, in practice, up to 4 items could be added to the EQ-5D to more comprehensively capture HRQoL aspects not covered by the instrument in specific populations.^{11,36,58-61} However, these choices have rarely been supported by sufficient empirical evidence. Our results indicate that in most cases 1 or 2 bolt-ons can enhance the discriminatory power of the instrument, and the inclusion of a third or fourth bolt-on has very little impact on measurement performance, although it could further improve content validity. This finding is in line with other important

considerations, such as respondent burden and feasibility for valuation.

There are some limitations of this study. First, it relied on a general population sample, and there were few respondents in the 2 most severe levels of each bolt-on item. Second, there was a block of other health-related questions positioned between the EQ-5D-5L and the bolt-ons,²¹ which could have potentially influenced responses on bolt-ons, and the fixed order of the 9 bolt-ons might have introduced some ordering effects. Third, the assessment of explanatory power of bolt-ons on HRQoL or well-being outcomes

might be affected by the heterogeneity in the interpretation and scoring of the EQ VAS^{62,63} and the content of the descriptive system of other instruments (eg, PROMIS Global Health, SWLS). Fourth, the use of LSSs alone for testing the known-group validity of the EQ-5D-5L versus EQ-5D-5L + bolt-on(s) may introduce bias given that combinations of responses that seem different in terms of overall severity may result in the same score. In addition, the known-group validity tests were restricted to health condition, age, general health, and well-being groups, but clinical severity was not evaluated. The absence of an adequate number of items representing cognition and the lack of items related to vision, hearing, breathing, or skin irritation represent a limitation of the CFA. The latter 4 bolt-on items were loaded on the same “other physical symptoms” factor. However, these items, in fact, capture different constructs, and if the survey had included condition-specific items covering these areas of HRQoL, they would likely have loaded on separate factors. Finally, our analyses involving external measures depend on the validity of these measures. It is worth noting that all instruments have been previously validated in Hungarian.^{23,24,64,65} Future research is recommended to use alternative approaches, such as item response theory, to gain a deeper understanding of the structural validity of the EQ-5D-5L and various bolt-ons in relevant populations.

Although several bolt-ons demonstrated strong performance in our study, it is uncertain whether these bolt-ons are suitable for valuation in terms of their descriptive characteristics and how these additional dimensions would affect the valuation tasks and the resulting utilities. For instance, previous valuation studies reported no benefit of adding a sleep or an energy dimension to the EQ-5D-3L.^{28,66} The valuation of the EQ-5D-5L with bolt-ons remains an unresolved issue and presents many analytical and practical challenges. Moreover, there is the issue of comparability of bolt-on value sets with existing national EQ-5D-5L value sets used in HTA. Presently, when separate bolt-on value sets are used for cost-utility analyses, HTA agencies (eg, National Institute for Health and Care Excellence or Canadian Agency for Drugs and Technologies in Health) typically treat the results as a sensitivity analysis to the reference case, EQ-5D.^{67,68} However, there is an increasing trend in using the EQ-5D for various noneconomic applications, such as observational studies, randomized controlled trials, patient registries, and population health surveys.⁶⁹ Given the brevity of the EQ-5D, extending it with a limited number of targeted questions seems a reasonable approach, which contrasts with the often 10 or more items found in broader generic, condition-specific, or well-being measures. This strategy allows for retaining the core 5 dimensions, ensuring international comparability and facilitating economic evaluations, while enhancing sensitivity in a selected context. Thus, the EQ-5D and an appropriate set of bolt-ons could even be a contender for condition-specific, generic profile HRQoL and well-being instruments.

Conclusions

Our study has provided valuable evidence supporting the validity of multiple bolt-ons for the EQ-5D-5L in a large general population sample. Incorporating relevant bolt-ons in population-based and patient surveys can improve the discriminatory power of the EQ-5D-5L. The addition of the vision and hearing bolt-on seems particularly valuable for more effectively capturing HRQoL decline with age. We have identified the most promising bolt-ons for 13 prevalent chronic health conditions, which can inform the selection of candidate bolt-ons for future studies in clinical populations.

Author Disclosures

Author disclosure forms can be accessed below in the [Supplemental Material](#) section.

Both authors are members of the EuroQoL Group. Views expressed in the article are those of the authors and are not necessarily those of the EuroQoL Research Foundation.

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REFERENCES

1. EuroQoL Group. EuroQoL-a new facility for the measurement of health-related quality of life. *Health Policy*. 1990;16(3):199-208.
2. Brooks R. EuroQoL BR: the current state of play. *Health Policy*. 1996;37(1):53-72.
3. Kennedy-Martin M, Slaap B, Herdman M, et al. Which multi-attribute utility instruments are recommended for use in cost-utility analysis? A review of national health technology assessment (HTA) guidelines. *Eur J Health Econ*. 2020;21(8):1245-1257.
4. Rencz F, Gulácsi L, Drummond M, et al. EQ-5D in Central and Eastern Europe: 2000-2015. *Qual Life Res*. 2016;25(11):2693-2710.
5. Brazier J, Connell J, Papaioannou D, et al. A systematic review, psychometric analysis and qualitative assessment of generic preference-based measures of health in mental health populations and the estimation of mapping functions from widely used specific measures. *Health Technol Assess*. 2014;18(34): vii-188.
6. Papaioannou D, Brazier J, Parry G. How valid and responsive are generic health status measures, such as EQ-5D and SF-36, in schizophrenia? A systematic review. *Value Health*. 2011;14(6):907-920.
7. Tosh J, Brazier J, Evans P, Longworth L. A review of generic preference-based measures of health-related quality of life in visual disorders. *Value Health*. 2012;15(1):118-127.

8. Mulhern BJ, Sampson C, Haywood P, et al. Criteria for developing, assessing and selecting candidate EQ-5D bolt-ons. *Qual Life Res.* 2022;31(10):3041–3048.
9. Geraerds AJLM, Bonsel GJ, Janssen MF, Finch AP, Polinder S, Haagsma JA. Methods used to identify, test, and assess impact on preferences of bolt-ons: a systematic review. *Value Health.* 2021;24(6):901–916.
10. Brennan VK, Jones G, Radley S, Dixon S. Incorporating process utility into cost-effectiveness analysis via a bolt-on domain to the SF-6D: an exploratory study. *Appl Health Econ Health Policy.* 2021;19(5):747–756.
11. Swinburn P, Lloyd A, Boye KS, Edson-Heredia E, Bowman L, Janssen B. Development of a disease-specific version of the EQ-5D-5L for use in patients suffering from psoriasis: lessons learned from a feasibility study in the UK. *Value Health.* 2013;16(8):1156–1162.
12. Hoogendoorn M, Oppe M, Boland MRS, Goossens LMA, Stolk EA, Rutten-van Mölken M. Exploring the impact of adding a respiratory dimension to the EQ-5D-5L. *Med Decis Mak.* 2019;39(4):393–404.
13. Chen G, Olsen JA. Filling the psycho-social gap in the EQ-5D: the empirical support for four bolt-on dimensions. *Qual Life Res.* 2020;29(11):3119–3129.
14. Yang Y, Rowen D, Brazier J, Tsuchiya A, Young T, Longworth L. An exploratory study to test the impact on three “bolt-on” items to the EQ-5D. *Value Health.* 2015;18(1):52–60.
15. Xu R, Luo N, Dong D. Examining performance of 20 Bolt-On items for the EQ-5D-5L for patients with 30 types of rare disease in China. Poster presented at the 40th EuroQol Plenary Meeting, Rome, Italy, Sept. 19–21, 2023.
16. Mao Z, Fan J, Rencz F, Yang Z, Luo N, Wang P. Developing and testing culturally relevant bolt-on items for EQ-5D-5L in Chinese populations: a mixed-methods study protocol. *BMJ Open.* 2024;14(1):e081140.
17. Kim SH, Jo MW, Ock M, Lee SI. Exploratory study of dimensions of health-related quality of life in the general population of South Korea. *J Prev Med Public Health.* 2017;50(6):361–368.
18. Thakumar AV, Shafie AA, Lim CJ. Exploration of EQ-5D-5L bolt-on items among Malaysian population. *Malays J Pharm (MJP).* 2017;3(1):8–17.
19. Kangwanrattanakul K, Gross CR, Sunantiwat M, Thavorncharoensap M. Exploration of a cultural-adaptation of the EQ-5D for Thai population: a “bolt-on” experiment. *Qual Life Res.* 2019;28(5):1207–1215.
20. Ng CCW, Cheung AWL, Wong E. PCR145 A qualitative exploratory study on developing and selecting potential bolt-on for the EQ-5D Hong Kong SAR, China. *Value Health.* 2023;26(6):S339.
21. Rencz F, Janssen MF. Analyzing the pain/discomfort and anxiety/depression composite domains and the meaning of discomfort in the EQ-5D: a mixed-methods study. *Value Health.* 2022;25(12):2003–2016.
22. Rencz F, Brodzsky V, Janssen MF. A direct comparison of the measurement properties of EQ-5D-5L, PROMIS-29+2 and PROMIS global health instruments and EQ-5D-5L and PROPR utilities in a general population sample. *Value Health.* 2023;26(7):1045–1056.
23. Jenei B, Bató A, Mitev AZ, Brodzsky V, Rencz F. Hungarian PROMIS-29+2: psychometric properties and population reference values. *Qual Life Res.* 2023;32(8):2179–2194.
24. Bató A, Brodzsky V, Mitev AZ, Jenei B, Rencz F. Psychometric properties and general population reference values for PROMIS Global Health in Hungary. *Eur J Health Econ.* 2023. Published online June 28.
25. Herdman M, Gudex C, Lloyd A, et al. Development and preliminary testing of the new five-level version of EQ-5D (EQ-5D-5L). *Qual Life Res.* 2011;20(10):1727–1736.
26. Krabbe PF, Stouthard ME, Essink-Bot ML, Bonsel GJ. The effect of adding a cognitive dimension to the EuroQol multiattribute health-status classification system. *J Clin Epidemiol.* 1999;52(4):293–301.
27. Finch AP, Brazier JE, Mukuria C, Bjorner JB. An exploratory study on using principal-component analysis and confirmatory factor analysis to identify bolt-on dimensions: the EQ-5D case study. *Value Health.* 2017;20(10):1362–1375.
28. Yang Y, Brazier J, Tsuchiya A. Effect of adding a sleep dimension to the EQ-5D descriptive system: a “bolt-on” experiment. *Med Decis Mak.* 2014;34(1):42–53.
29. Cella D, Choi SW, Condon DM, et al. Promis[®] adult health profiles: efficient short-form measures of seven health domains. *Value Health.* 2019;22(5):537–544.
30. Ware Jr JE, Sherbourne CD. The MOS. 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. *Med Care.* 1992;30(6):473–483.
31. Hays RD, Bjorner JB, Revicki DA, Spritzer KL, Cella D. Development of physical and mental health summary scores from the patient-reported outcomes measurement information system (PROMIS) global items. *Qual Life Res.* 2009;18(7):873–880.
32. Diener E, Emmons R, Larsen R, Griffin S. The satisfaction with life scale. *J Pers Assess.* 1985;49(1):71–75.
33. Brazier J, Roberts J, Deverill M. The estimation of a preference-based measure of health from the SF-36. *J Health Econ.* 2002;21(2):271–292.
34. Evans JD. *Straightforward Statistics for the Behavioral Sciences.* Thomson, Canada: Brooks/Cole Publishing Co; 1996.
35. de Graaf JA, Kuijpers M, Visser-Meily J, Kappelle LJ, Post M. Validity of an enhanced EQ-5D-5L measure with an added cognitive dimension in patients with stroke. *Clin Rehabil.* 2020;34(4):545–550.
36. Geraerds A, Polinder S, Spronk I, et al. Sensitivity of the EQ-5D-5L for fatigue and cognitive problems and their added value in Q-fever patients. *Qual Life Res.* 2022;31(7):2083–2092.
37. Ophuis RH, Janssen MF, Bonsel GJ, Panneman MJ, Polinder S, Haagsma JA. Health-related quality of life in injury patients: the added value of extending the EQ-5D-3L with a cognitive dimension. *Qual Life Res.* 2019;28(7):1941–1949.
38. Koszórú K, Hajdu K, Brodzsky V, et al. Comparing the psychometric properties of the EQ-5D-3L and EQ-5D-5L descriptive systems and utilities in atopic dermatitis. *Eur J Health Econ.* 2023;24(1):139–152.
39. Rencz F, Mukuria C, Bató A, Poór AK, Finch AP. A qualitative investigation of the relevance of skin irritation and self-confidence bolt-ons and their conceptual overlap with the EQ-5D in patients with psoriasis. *Qual Life Res.* 2022;31(10):3049–3060.
40. Szlávicz E, Szabó Á, Kinyó Á, et al. Content validity of the EQ-5D-5L with skin irritation and self-confidence bolt-ons in patients with atopic dermatitis: a qualitative think-aloud study. *Qual Life Res.* 2024;33(1):101–111.
41. Spronk I, Bonsel GJ, Polinder S, van Baar ME, Janssen MF, Haagsma JA. Exploring the relation between the EQ-5D-5L pain/discomfort and pain and itching in a sample of burn patients. *Health Qual Life Outcomes.* 2020;18(1):144.
42. Finch AP, Mulhern B. Where do measures of health, social care and wellbeing fit within a wider measurement framework? Implications for the measurement of quality of life and the identification of bolt-ons. *Soc Sci Med.* 2022;313:115370.
43. Wilson IB, Cleary PD. Linking clinical variables with health-related quality of life. A conceptual model of patient outcomes. *JAMA.* 1995;273(1):59–65.
44. Kaiser HF. The application of electronic computers to factor analysis. *Educ Psychol Meas.* 1960;20(1):141–151.
45. Rosseel Y. lavaan: an R package for Structural Equation Modeling. *J Stat Softw.* 2012;48(2):1–36.
46. Li CH. The performance of ML, DWLS, and ULS estimation with robust corrections in structural equation models with ordinal variables. *Psychol Methods.* 2016;21(3):369–387.
47. Comrey AL, Lee HB. *A First Course in Factor Analysis.* 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc; 1992.
48. Hu LT, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. *Struct Equ Model Multidiscip J.* 1999;6(1):1–55.
49. Schreiber JB, Nora A, Stage FK, Barlow EA, King J. Reporting structural equation modeling and confirmatory factor analysis results: a review. *J Educ Res.* 2006;99(6):323–338.
50. Watt T, Groenvold M, Deng N, et al. Confirmatory factor analysis of the thyroid-related quality of life questionnaire ThyPRO. *Health Qual Life Outcomes.* 2014;12:126.
51. Janssen MF, Bonsel GJ, Luo N. Is EQ-5D-5L better than EQ-5D-3L? A head-to-head comparison of descriptive systems and value sets from seven countries. *Pharmacoeconomics.* 2018;36(6):675–697.
52. Feng YS, Jiang R, Pickard AS, Kohlmann T. Combining EQ-5D-5L items into a level summary score: demonstrating feasibility using non-parametric item response theory using an international dataset. *Qual Life Res.* 2022;31(1):11–23.
53. Gandhi M, Ang M, Teo K, et al. A vision “bolt-on” increases the responsiveness of EQ-5D: preliminary evidence from a study of cataract surgery. *Eur J Health Econ.* 2020;21(4):501–511.
54. Luo N, Wang X, Ang M, et al. A vision “bolt-on” item could increase the discriminatory power of the EQ-5D index score. *Value Health.* 2015;18(8):1037–1042.
55. Wang P, Chong SL, Tan RL, Luo N. A hearing bolt-on item increased the measurement properties of the EQ-5D-5L in a community-based hearing loss screening program. *Eur J Health Econ.* 2023;24(3):393–398.
56. Dijkshoorn JN, Haagsma JA, van der Vlies CH, Hop MJ, van Baar ME, Spronk I. Assessing health-related quality of life of adult patients with intermediate burns: the added value of an itching and cognition item for the EQ-5D: a retrospective observational study. *European Burn Journal.* 2022;3(2):264–277.
57. Pickard AS, Gooderham M, Hartz S, Nicolay C. EQ-5D health utilities: exploring ways to improve upon responsiveness in psoriasis. *J Med Econ.* 2017;20(1):19–27.
58. Spronk I, Bonsel GJ, Polinder S, van Baar ME, Janssen MF, Haagsma JA. The added value of extending the EQ-5D-5L with an itching item for the assessment of health-related quality of life of burn patients: an explorative study. *Burns.* 2021;47(4):873–879.
59. Xu RH, Dong D, Luo N, Yang R, Liu J, Zhang S. Investigating the added value of the EQ-5D-5L with two bolt-on items in patients with hemophilia. *Front Med (Lausanne).* 2021;8:707998.
60. Viswanath N, Harichandra Kumar KT, Haridasan S, Parameswaran S, Priyamvada PS. Functional status in hemodialysis-a comparative study with FIM, ADLQ and 7D5L instruments. *Indian J Nephrol.* 2019;29(3):172–178.
61. Chen G, Olsen JA. Extending the EQ-5D: the case for a complementary set of 4 psycho-social dimensions. *Qual Life Res.* 2023;32(2):495–505.
62. Busschbach J, Hessing D, de Charro F. Chapter 7. Observations on one hundred students filling in the EuroQol questionnaire. In: Kind P, Brooks R, Rabin R, eds. *EQ-5D Concepts and Methods: A Developmental History.* Dordrecht, Netherlands: Springer; 2005:81–90.

63. Tan RL, Yang Z, Igarashi A, Herdman M, Luo N. How do respondents interpret and view the EQ-VAS? A qualitative study of three Asian populations. *Patient*. 2021;14(2):283–293.
64. Czibalmos Á, Nagy Z, Varga Z, Huszti P. Páciens megelégedettségi vizsgálat SF-36 kérdőívvel, a magyarországi normálértékek meghatározása. Article in Turkish. *Népegészségügy*. 1999;80(1):4–19.
65. Martos T, Sallay V, Désfalvi J, Szabó T, Iltzész A. Psychometric characteristics of the Hungarian version of the Satisfaction with Life Scale (SWLS-H). *Mentalhig Pszichol*. 2014;15(3):289–303.
66. Gudex C. Are we lacking a dimension of energy in the EuroQol Instrument?. In: Bjork S, ed. *EuroQol Conference Proceedings, Lund*. 1992. Lund: Swedish Institute for Health Economics; 1991:61–72. IHE Working Paper 92:2.
67. National Institute for Health and Care Excellence. Single technology appraisal-ixekizumab for treating moderate to severe plaque psoriasis. <https://www.nice.org.uk/guidance/ta442/documents/committee-papers-3>. Accessed January 27, 2024.
68. CADTH. CADTH Common Drug Review. Pharmacoeconomic Review Report: Guselkumab (Tremfya): (Janssen Inc.). Indication: for the treatment of adult patients with moderate-to-severe plaque psoriasis who are candidates for systemic therapy or phototherapy. https://www.cadth.ca/sites/default/files/cdr/pharmacoeconomic/SR0530_Tremfya_PE_Report.pdf. Accessed January 27, 2024.
69. Wang A, Rand K, Yang Z, Brooks R, Busschbach J. The remarkably frequent use of EQ-5D in non-economic research. *Eur J Health Econ*. 2022;23(6):1007–1014.