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An IRT-constructed Brief Physical Functioning Scale and Its Association with Health Status

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Abstract **Background**: This study used item response theory (IRT) to create a brief PF scale (BPFS) and subsequently examined its relationship with several health characteristics. **Methods**: Data were used from *N*=1,716 adults 50+ years of age participating in a large health survey. A pool of 19 PF items were dichotomized to either 1 (any amount of difficulty) or 0 (no difficulty). A 2-parameter logistic (2PL) IRT model was used to evaluate item fit to the unidimensional PF construct. Criteria used to eliminate an item was 1) a small discrimination (slope) parameter, 2) a significant chi-square statistic for cell residuals, and 3) a large root mean square error of approximation (RMSEA). The IRT model was continually re-fitted until all remaining items met criteria. SAS PROC IRT and R ltm were used for scale construction. **Results**: The IRT analysis resulted in 8 well-fitting items with large item discrimination (*a*s > 2.03), moderate item difficulty range (*b*s: -0.07 - 1.35), and adequate item fit (RMSEAs < .036). After full adjustment, each additional BPFS point significantly (*p*s < .05) increased stepwise the odds of reporting poor HRQOL (*OR* = 1.59), being depressed (*OR* = 1.46), having thoughts of suicide (*OR* = 1.35), not meeting PA guidelines (*OR* = 1.29), being BMI-obese (*OR* = 1.23), being WC-obese (*OR* = 1.13), experiencing poor sleep (*OR* = 1.29), and reporting sleepiness (*OR* = 1.16). **Conclusion**: Results from this study show that the IRT-constructed BPFS is an efficient and valid tool that can predict health status in older adults.

Keywords: *physical functioning, Item response theory (IRT), psychometrics, aging and health*

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1. Introduction

Physical functioning (PF) is the ability to engage in daily activities of varying importance. [1] The proper assessment of PF is important to health professionals due to the strong links between PF and injury, illness, and mortality. [2,3,4] Several objective measures of PF are used in research and practice and include grip strength, walking speed, chair raises, and standing balance tests. [5] When direct participant examination is not possible, however, a very popular PF assessment alternative is the use of self-reported assessments. Despite widespread use of subjective PF scales, many have limitations. Such limitations include the length of the scale (too many items), lack of specificity of the scale (included with other irrelevant subscales), and lack of structural and content validity of the scale. [6] In particular, considering the populations that are often administered a self-report PF instrument (i.e., elderly, disabled, diseased, etc.), brief and parsimonious scales with adequate psychometric properties become especially important characteristics. [7]

Classical test theory (CTT) is the most common and conventional model used by researchers to validate self-reported scales. [8] The focus of CTT is placed on the unweighted sum of responses across items of an instrument, otherwise known as the observed score. A more modern approach to scale development and validation, which can complement CTT-based research, is item response theory (IRT). IRT provides a system of mathematical equations which can model the relationship between latent traits and observed responses to items.[9] In this context, IRT models can assess the functioning of each item to determine how well they perform in measuring the trait of interest. In similar fashion, IRT can be used to remove poor functioning items from a scale - thereby creating a more parsimonious version of the original scale. The purpose of this study was to firstly use IRT to create a brief PF scale (BPFS) and secondly to examine the relationship between BPFS scores and several different health characteristics.

2. Materials & Methods

2.1. Study Procedures

Data were used from adults 50+ years of age participating in the 2015-2016 National Health and Nutrition Examination Survey (NHANES). The NHANES protocol includes a multistage stratified sampling from the

non-institutionalized population. [10] The purpose of NHANES is to assess health behavior, health status, and nutrition of civilian residents. The NHANES data come from personal interviews, standardized physical examinations, and laboratory tests. The current study used data only from personal interviews (demographic data and questionnaire data) and physical examinations (body measures data).

2.2. PF Items

PF items included in the questionnaire module ask participants about their level of difficulty performing various tasks. A pool of 19 PF items commonly used to assess PF were used in this study. [11] Each PF item was dichotomized to either 1 (reported any amount of difficulty) or 0 (reported no difficulty). Additionally, a PF score was computed using the new 8-item BPFS with a score ranging from 0 to 8.

2.3. Health Status Variables

A total of eight (8) health status variables were used in this study and included health-related quality of life (HRQOL), Patient Health Questionnaire (PHQ9) score, suicide ideation (SI), moderate-to-vigorous physical activity (MVPA), body mass index (BMI), waist circumference (WC), sleep quality (SQ), and sleepiness frequency (SF). HRQOL was assessed from a question asking about perceived general health ranging from 1 (excellent) to 5 (poor). HRQOL was also converted to binary form indicating "poor" health ("fair" and "poor"). PHQ9 is a depression symptom scale with an overall score ranging from 0 (not depressed) to 27 (more depressed). PHQ9 was also converted to binary form indicating "being depressed" (PHQ9 score $\geq$ 10). SI was assessed from a single PHQ9 question asking participants how often they felt that they would be better off dead, ranging from 0 (not at all) to 3 (nearly every day). A binary SI variable was created indicating having any thoughts of suicide at all.

MVPA was assessed using two different PA variables. Moderate PA (MPA, min/wk) was assessed from questions asking respondents about the number of days per week and number of minutes on average they engaged in moderate-intensity sports, fitness, or recreational activities causing small increases in breathing or heart rate. Vigorous PA (VPA, min/wk) was assessed similarly but regarding activities of vigorous-intensity causing large increases in breathing or heart rate. MVPA (min/wk) was assessed by adding MPA to 2 × VPA. MVPA was also converted to binary form indicating "meeting PA guidelines" (150+ min/wk of MVPA). WC was assessed by a trained health professional just above the uppermost lateral border of the right ilium at the midaxillary line.[12] WC was also converted to binary form indicating obesity for males (WC > 102 cm) and females (WC > 88 cm). BMI was measured from participant's height and weight with weight measured on a digital scale and height measured using a stadiometer.[12] BMI was also converted to binary form indicating obesity (BMI $\geq$ 30). SQ was assessed from a single question asking participants if they ever told a doctor they had trouble sleeping. A binary SQ variable was created indicating "poor" SQ (responding "yes"). SF was assessed from a single question asking how often they feel overly sleepy during the day. A binary SF variable was created indicating "often" (5 to 30 times a month).

2.4. Demographic Variables

In order to control for possible demographic confounding, sex, age, race, and income were used in this study. Sex was a categorical variable represented by two groups: 1) males and 2) females. Age was a numeric variable ranging from 50 to 80+ years. Race was a categorical variable and comprised the following four groups: 1) Non-Hispanic White, 2) Non-Hispanic Black, 3) Mexican/Hispanic, and 4) Other Races / Multi-racial. Finally, income was a numeric variable, collected as family income, and comprised twelve different income brackets ranging from 1 = $0 to $4,999 to 12 = $100,000 and over.

2.5. Statistical Analyses

The statistical analysis plan was separated into two stages. Stage I concerned the development of a parsimonious PF scale (BPFS). Stage II concerned examining the relationship between BPFS scores and health status variables. For stage I, a 2-parameter logistic (2PL) IRT model was fit to the 19-item PF scale data to identify poor functioning items. [13] Criteria used to eliminate an item was 1) a small discrimination (slope) parameter, 2) a significant chi-square statistic for cell residuals, and 3) a large root mean square error of approximation (RMSEA). The IRT model was continually re-fitted until all remaining items met criteria. A factor analysis was also performed post-hoc on the BPFS to ensure the new scale represented a unidimensional trait. The eigenvalue greater than 1.00 criteria was used to retain factors. [14] Additionally, item-test correlations, Kuder-Richardson Formula 20 (KR-20), and KR-20 with item deleted were used to examine validity of scale items. [15] For stage II, multivariate logistic regression was used to estimate the BPFS-related odds of having poor health status. [16] Analyses were weighted to produce generalizations representative of the larger noninstitutionalized population of adults aged 50–80+ years. [17] SAS PROC IRT and R ltm were used for scale construction. [18,19]

3. Results

A total of N = 1,716 (N_{male} = 844, N_{female} = 872) participants had complete PF data for stage I of the study. Table 1 contains parameter estimates and related statistics from the 2PL IRT model for the new BPFS. The IRT analysis resulted in 8 well-fitting items with large item discrimination (as > 2.03), moderate item difficulty range (bs: -0.07 - 1.35), and adequate item fit (RMSEAs < .036). Item 6 had the largest item discrimination (a = 5.51), indicating that the ability to do house chores can separate individuals with even small differences in PF. Item 2 had the smallest item difficulty (b = -0.07), indicating that individuals lower on the PF trait (i.e., better PF) have equal chance of having difficulty stooping, crouching, or kneeling. Conversely, item 7 had the largest item

difficulty (b = 1.35), indicating that individuals higher on the PF trait (i.e., poorer PF) have equal chance of having difficulty preparing meals.

Table 2 contains simple item statistics and bivariate correlation coefficients for the new BPFS. Mean values indicate the proportion of participants endorsing each item and shows items 7 and 8 with the lowest numbers and item 2 with greatest number of endorsements. Additionally, item correlations all indicate adequate convergence with values ranging from r = .287 to r = .629. Table 3 contains results from the factor analysis and reliability analysis of the BPFS. Factor analysis of the BPFS polychoric correlation matrix retained a single factor with high explained variance of 76% and all loadings greater than .77. Additionally, internal consistency reliability was strong (KR-20 = .87) with no improvement in reliability for any one item deleted.

Table 4 contains descriptive statistics on all variables related to stage II of the study. BPFS scores were relatively low with *Mean* = 1.9 (*SD* = 2.3) for male and *Mean* = 2.5 (*SD* = 2.5) for female participants. Table 5 contains multivariate logistic regression results for the relationship between BPFS scores and health status variables. Fully adjusted models showed that each additional BPFS point significantly increased stepwise the odds of reporting poor HRQOL (*OR* = 1.59, p < .001), being depressed (*OR* = 1.46, p < .001), having thoughts of suicide (*OR* = 1.35, p = .001), not meeting PA guidelines (*OR* = 1.29, p < .001), being BMI-obese (OR = 1.23, p < .001), being WC-obese (*OR* = 1.13, p = .017), experiencing poor sleep (*OR* = 1.29, p < .001), and reporting sleepiness (*OR* = 1.16, p < .001).

Table 1. Two-parameter logistic (2PL) IRT constructed brief physical functioning scale (BPFS) item parameters and statistics (*N* = 1,716)

	Discrimination		Difficulty		Statistics	
BPFS Item	*a*	*SE*	*b*	*SE*	r_{Theta}	*RMSEA*
Item 1: Attending social event difficulty	2.917	0.212	1.018	0.046	.664	.011
Item 2: Stooping, crouching, kneeling difficulty	2.493	0.166	-0.071	0.037	.739	.000
Item 3: Standing for long periods difficulty	3.186	0.227	0.084	0.035	.789	.000
Item 4: Reaching up over head difficulty	2.033	0.137	1.003	0.053	.608	.018
Item 5: Lifting or carrying difficulty	3.182	0.222	0.647	0.038	.744	.000
Item 6: House chores difficulty	5.507	0.568	0.622	0.034	.807	.000
Item 7: Preparing meals difficulty	3.132	0.264	1.346	0.055	.596	.000
Item 8: Walking between rooms on same floor	4.089	0.398	1.273	0.049	.632	.036

Note. a is discrimination parameter. b is difficulty parameter. r_{Theta} is Pearson correlation coefficient between IRT person score (theta) and participant response to respective item. SE is standard error.

Table 2. IRT constructed brief physical functioning scale (BPFS) item statistics and bivariate correlation coefficients (*N* = 1,716)

Item	*Mean*	*SD*	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8
Item 1: Attending social event difficulty	.192	.394	1	.357	.414	.392	.460	.551	.493	.528
Item 2: Stooping, crouching, kneeling difficulty	.525	.500		1	.543	.381	.435	.479	.287	.313
Item 3: Standing for long periods difficulty	.474	.499			1	.383	.497	.549	.335	.376
Item 4: Reaching up over head difficulty	.223	.417				1	.478	.460	.353	.390
Item 5: Lifting or carrying difficulty	.288	.453					1	.629	.430	.452
Item 6: House chores difficulty	.280	.449						1	.500	.518
Item 7: Preparing meals difficulty	.120	.325							1	.507
Item 8: Walking between rooms on same floor	.121	.326								1

Note. Item means are interpreted as the proportion endorsing each item.

Table 3. Factor loadings and eigenvalues of the polychoric correlation matrix for the IRT constructed brief physical functioning scale (BPFS) (*N* = 1,716)

	loading	h^2	r_{Total}	$KR\text{-}20_{del}$	KR-20
Attending social event difficulty (SE)	.864	.746	.632	.848	.866
Stooping, crouching, kneeling difficulty (SCK)	.826	.682	.544	.857	
Standing for long periods difficulty (SLP)	.882	.778	.610	.850	
Reaching up over head difficulty (ROH)	.767	.588	.553	.856	
Lifting or carrying difficulty (LC)	.882	.778	.674	.843	
House chores difficulty (HC)	.955	.913	.743	.835	
Preparing meals difficulty (PM)	.879	.772	.568	.855	
Walking between rooms on same floor (WBR)	.923	.853	.607	.850	
Eigenvalue	6.109				
% explained	0.764				

Note. h^2 is communality. r_{Total} is correlation between item response and scale total. *KR-20* is the Kuder-Richardson Formula 20 reliability coefficient. One factor was retained by the eigenvalue > 1.0 criterion.

Table 4. Descriptive statistics on study variables by sex

Sample	Variable	*N*	*Min*	*Max*	*Median*	*Mean*	*SD*	*CV*
Males	Age	844	50.0	80.0	67.0	67.5	8.0	11.8
	HRQOL	777	1.0	5.0	3.0	3.0	1.0	32.2
	PHQ9	764	0.0	24.0	1.5	3.1	4.3	137.9
	SI	769	0.0	3.0	0.0	0.1	0.3	518.6
	MVPA	842	0.0	2700.0	0.0	163.1	330.5	202.6
	BMI	800	16.4	57.4	28.2	29.0	5.9	20.3
	WC	765	67.6	169.6	103.7	104.9	14.9	14.2
	SQ	844	1.0	2.0	2.0	1.7	0.5	27.3
	SF	844	0.0	9.0	2.0	1.7	1.2	73.0
	BPFS	844	0.0	8.0	1.0	1.9	2.3	120.1
Females	Age	872	50.0	80.0	67.0	67.3	8.3	12.3
	HRQOL	798	1.0	5.0	3.0	3.0	1.0	32.3
	PHQ9	784	0.0	25.0	2.0	3.7	4.5	121.4
	SI	786	0.0	3.0	0.0	0.1	0.3	635.0
	MVPA	867	0.0	4800.0	0.0	114.9	291.0	253.2
	BMI	827	15.5	64.5	29.4	30.4	7.4	24.2
	WC	786	67.4	164.0	100.8	102.0	15.4	15.1
	SQ	872	1.0	2.0	2.0	1.6	0.5	30.6
	SF	872	0.0	9.0	2.0	1.7	1.2	71.8
	BPFS	872	0.0	8.0	2.0	2.5	2.5	99.4

Note. HRQOL is self-reported general health ranging from 1 (excellent) to 5 (poor). PHQ9 is the patient health questionnaire score ranging from 0 (lowest depression) to 27 (highest depression). SI is suicide ideation ranging from 0 (never) to 3 (nearly every day). MVPA is self-reported moderate-to-vigorous recreational physical activity (min). BMI is body mass index (kg/m^2). WC is waist circumference (cm). SQ is sleep quality assessed as 1 (poor) or 2 (good). SF is sleepiness frequency from 0 (never) to 4 (almost always). BPFS is the new 8 item physical functioning score ranging from 0 (no problems with PF) to 8 (highest amount of problems with PF). Min is minimum value. Mean is average. SD is standard deviation. CV is coefficient of variation. Max is maximum value.

Table 5. Relationship between BPFS score and health status variables

	Model I			Model II			Model III		
Outcome	*OR*	95% *CI*		*OR*	95% *CI*		*OR*	95% *CI*	
Poor health (HRQOL)									
No	1.00			1.00			1.00		
Yes	1.60	1.46	1.74	1.58	1.45	1.71	1.59	1.43	1.78
Depressed (PHQ9)									
No	1.00			1.00			1.00		
Yes	1.57	1.44	1.71	1.52	1.39	1.67	1.46	1.28	1.67
Thoughts of suicide (SI)									
No	1.00			1.00			1.00		
Yes	1.45	1.30	1.62	1.44	1.26	1.64	1.35	1.15	1.58
Meets PA guidelines (MVPA)									
Yes	1.00			1.00			1.00		
No	1.39	1.28	1.50	1.39	1.28	1.50	1.29	1.18	1.42
Obese (BMI)									
No	1.00			1.00			1.00		
Yes	1.24	1.15	1.34	1.23	1.14	1.32	1.23	1.13	1.33
Obese (WC)									
No	1.00			1.00			1.00		
Yes	1.18	1.07	1.30	1.19	1.08	1.31	1.13	1.03	1.25
Poor sleep (SQ)									
No	1.00			1.00			1.00		
Yes	1.31	1.24	1.39	1.30	1.23	1.37	1.29	1.22	1.36
Sleepy often (SF)									
No	1.00			1.00			1.00		
Yes	1.18	1.09	1.27	1.17	1.09	1.25	1.16	1.08	1.25

Note. Model I is crude model. Model II is age adjusted. Model III is fully adjusted for age, sex, race, and income.

4. Discussion

The first purpose of this study was to use IRT to create a shortened PF scale from a larger pool of items contained in the NHANES PF module. Results from this study clearly support the BPFS as a well-developed and parsimonious assessment of PF with considerable measurement properties. Specifically, the BPFS is shorter than the original scale with a total of 8 items as compared to the original pool of 19 items. Additionally, BPFS items were shown to be high functioning in that they each discriminate well across the PF trait. Finally, measurement properties of the BPFS were reinforced post-hoc with evidence supporting its construct validity and internal consistency reliability. These optimal findings are not unexpected as other studies have also developed shortened scales of high measurement quality using similar fit criteria and modern psychometric theory [20,21,22].

The second purpose of this study was to examine the relationship between the new scale scores from the BPFS and several different health characteristics. Results from this stage of the research overwhelmingly support a PF and health status relationship, with all health status variables predicted by BPFS scores in their hypothesized direction. That is, as PF declined in older adults the likelihood of poor health status increased. Much research in the published literature reinforce the influence that PF has on depression, suicide ideation, obesity, sleep quality, and physical activity. [23,24,25,26,27] Given this agreement, this study additionally shows that scores from the BPFS are able to detect differences in groups with contrasting health characteristics.

The strengths of this study relate to the research design and statistical methods. That is, NHANES uses a complex survey design that ensures the inferences from this study represent the larger population of noninstitutionalized older adults. Additionally, measures of obesity used in this study were objectively assessed by trained health practitioners. Finally, this study used IRT for scale development and validation, which is an advanced, modern, and novel psychometric tool. There are also limitations worth mentioning. Many of the health status variables used in this study (i.e., HRQOL, PHQ9, SI, SQ, SF, and MVPA) were assessed subjectively via questionnaire and may include measurement error not accounted for. Therefore, future research should focus on studying the relationship between the BPFS and objective health status measures, such as PA assessed via accelerometry and biometric health measures. Since PF was also assessed via questionnaire in this study, future research should focus on validating BPFS scores against objective PF measures such as grip strength, walking speed, chair stands, and balance tests. Finally, this study is cross-sectional in nature and therefore findings do not reflect cause-and-effect relationships between PF and health status.

5. Conclusions

Results from this study show that the IRT-constructed BPFS is an efficient and valid tool that can predict health status in older adults. Health professionals should consider using the BPFS as a more parsimonious scale option in assessing PF in older adult populations.

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