Validating intrinsic capacity to measure healthy aging in an upper middle-income country: Findings from the ELSI-Brazil

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Summary

Background While efforts have been made to validate intrinsic capacity (IC) as a multidimensional indicator of healthy aging in high-income countries, we still need evidence from lower-income countries. We examined associations of IC with wide ranges of activities of daily living in a nationally representative sample of Brazilians aged≥50 years.

Methods This cross-sectional analysis included 7175 participants from the Brazilian Longitudinal Study of Aging. IC domains (cognitive, psychological, sensory, locomotor, and vitality) were determined using self-reported and physical performance measures. IC was operationalized through factorial analysis. We investigated associations of IC and its domains with functional ability in basic, instrumental, and advanced activities of daily living (ADL, IADL, and AADL) using logistic regressions adjusted for sociodemographic, clinical, and modifiable risk factors.

Findings The IC bi-factorial model revealed satisfactory goodness-of-fit. Preserved ability in ADL and IADL, respectively, ranged from 69% and 29% to 89% and 74% across IC quartiles. In adjusted analyses, every standard deviation increment in IC composite score was associated with almost twice the odds of preserved ADL (OR=1·72; 95%CI=1·54-1·93), preserved IADL (OR=1·95; 95%CI=1·77-2·16), and high performance in AADL (OR=1·79; 95%CI=1·59-2·00). Similar results were reported using the IC domains as predictors. Although age, race/ethnicity, and education did not modify associations of IC with functional ability, we found sex differences with stronger relationships of IC with preserved ADL or IADL in females.

Interpretation Our results support IC validity and reliability to measure healthy aging in diverse socioeconomic and cultural settings. Incorporating IC in routine practices can promote holistic and person-centered care approaches in aging societies.

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Abbreviations: IC, Intrinsic Capacity; ADL, Activities of Daily Living; IADL, Instrumental Activities of Daily Living; AADL, Advanced Activities of Daily Living; ELSI-Brazil, The Brazilian Longitudinal Study of Aging; LMICs, Low- and Middle-income Countries; CES-D, Center for Epidemiologic Studies Depression Scale

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Research in context

Evidence before the study

We searched PubMed for articles published up to April 30, 2022, using the search terms "intrinsic capacity", "functional ability", "activities of daily living", "disability", "healthy aging", "aging", "socioeconomic factors", and "gender differences", with no language restrictions. In 2015, envisioning global actions for the Decade of Healthy Aging (2021-2030), the World Health Organization proposed the new construct of intrinsic capacity (IC) as a multidimensional indicator encompassing mental and physical capacities that might contribute to healthy aging. The IC construct integrates five domains (i.e., cognitive, psychological, sensory, locomotor, and vitality). Recent studies in England, the United States, and China applying this framework showed that the composite IC measure was associated with declining performance in basic and instrumental activities of daily living (ADL and IADL). However, before the IC can be incorporated into clinical practice worldwide, we still need more information supporting its validity and reliability. For example, the associations of the five domains, under the IC construct, with activities of daily living were not examined. We also do not know whether sociodemographic factors (e.g., age, sex, race/ethnicity, education) modify the relationship between IC and functional ability. This aspect is fundamental to keeping the consistency of IC in people living in low- and middle-income countries (LMICs), where this framework was seldom tested. Moreover, although social and relational tasks (e.g., keeping contact with others, playing games, traveling, organizing social events) are essential for wellbeing in late life, the associations of IC with such advanced activities of daily living (AADL) remains uncertain.

Added value of the study

The concept of IC, rather than the chronological age, is a promising element to capture the heterogeneity of the older population Our findings in 7,175 individuals from a nationally representative sample of Brazilians aged $\geq$ 50 years showed that the composite IC measure is highly associated with the full range of routine activities, from self-care to participation, entertainment, and social interactions essential for older adults' wellbeing. We also determined that the strong relationship between IC and functional performance builds on the significant associations of its five domains (i.e., cognitive, psychological, sensory, locomotor, and vitality) with ADL, IADL, and AADL. Interestingly, our results based on an ethnically and socially diverse population from an upper middle-income country showed that age, race/ethnicity, and education level did not modify the associations of IC with functional ability. Nevertheless, we observed significant sex differences, with a stronger relationship of IC with preserved ADL or IADL in females.

Implications of all the available evidence

A growing body of evidence supports the validity and reliability of IC to measure healthy aging in diverse socioeconomic and cultural populations. Incorporating IC into practice represents a unique opportunity to shift from the traditional disease-based perspective towards holistic assessments and integrated care responsive to the needs of our aging societies. Future studies aiming to examine the impact of IC changes over time and investigate whether applying IC improves health outcomes in older people are warranted.

Introduction

Nearly 70% of the global older population live in low- and middle-income countries (LMICs), rising to 80% by 2050.[1] Health conditions in older people are usually due to interactions between multiple chronic diseases, socioeconomic and environmental factors, and age-related impairments, demanding continuous and integrative care.[2] Because of the expected increase in the number of older people worldwide, particularly in LMICs, the prevalence of such health conditions is likely to rise, putting these countries under substantial economic and societal strain.[3] The promotion of healthy aging and the prevention of underlying conditions affecting older people could help mitigate the burden of age-related morbidity in low-resourced settings.[4]

Intrinsic capacity (IC) has recently been proposed by the World Health Organization (WHO) as a multidimensional indicator of health, accounting for mental and physical capacities that are crucial to older people to continue doing what they value most.[2] The IC framework comprises five domains (cognitive, psychological, sensory, locomotor, and vitality).[4,5] This holistic concept can provide a better understanding of different aging pathways and thereby capture heterogeneity, a hallmark of the older population. It might also work as a positive parameter to measure health and guide health professionals to improve older adults' wellbeing.[2,3] However, before the IC construct can be globally incorporated into practice, more

research is needed to validate its conceptual natures across different populations (e.g., young-old, populations with different income and societal structures).[6-8]

Beard et al. (2019) computed a total composite score using a bi-factor model based on the five IC domains and found it to be a reliable tool to predict incident ADL and IADL disability among community-dwelling older people in the United Kingdom.[6] Similar findings were observed among older adults living in the United States.[7] More recently, a few longitudinal studies conducted with older adults living in low-income areas found that IC predicted functional decline based on basic and instrumental activities of daily living (ADL and IADL).[8,9] Nonetheless, there is a need for further exploring the associations of IC and its five domains with the full range of routine activities, which expresses the ability of individuals to interact with the environment and to do what they value most in life.[8] For example, although social and relational tasks (e.g., planning events, playing games, traveling) are essential for wellbeing in late life, the relationship between IC and such advanced activities of daily living (AADL) remains uncertain. We also do not know whether social determinants of health change how IC connects to functional ability, a fundamental aspect to keep the consistency of the construct in low-resourced areas.[10] Additionally, multiple mechanisms start to play a long-term role on healthy aging since midlife. However, it is still not clear whether IC is a reliable measure of health in middle-aged individuals.[6-8]

In this study, we used data of the Brazilian Longitudinal Study of Aging, a nationally representative sample of people aged ≥50 years, to explore the IC construct in an ethnically and socially diverse population from Latin America. We aimed to (1) operationalize an IC measure using factor analysis; (2) investigate the associations of IC and its domains with a wide range of activities of daily living; and (3) examine whether this relationship is modified by sociodemographic factors. Besides having an independent association with preserved ADL and IADL, we hypothesized that higher IC scores (composite and specific domains) would correlate with better performance in productive and leisure-time activities (i.e., AADL), a core aspect of older adults' wellbeing. We also hypothesized that the IC would have a greater influence on executing routine activities in minorities affected by socioeconomic disadvantage and environmental barriers (e.g., woman, black race/ethnicity, lower levels of education) compared to persons with better socioeconomic status, holding more environmental resources to deal with the challenges imposed by low IC.

Methods

Study design and population

This is a cross-sectional study using data from the baseline assessment of the ongoing Brazilian Longitudinal Study of Aging (ELSI-Brazil), which adopts a conceptual framework and approach common to other large-scale longitudinal studies of aging in the world, such as the Health and Retirement Study.[11] The study baseline, conducted in 2015-2016, comprised 9,412 individuals aged ≥50 years from the five Brazilian macro-regions. Trained interviewers conducted the home-based surveys that included comprehensive information on health, economic, and social factors. Follow-up assessments are expected to take place every 3-4 years. Further details about the ELSI-Brazil can be found elsewhere.[11,12]

The Oswaldo Cruz Foundation Minas Gerais ethics committee approved the study. Informed consent was obtained from all participants prior to enrollment.

For this study, we excluded individuals who were chronically bedridden (n=104) or unable to perform physical tests (n=569). As the IC construct focuses on residual wellness of the organism with a primary interest in healthy aging, including individuals experiencing severe disability would not offer meaningful information to this study.[4] We also excluded those who had missing information on variables from the IC construct (n=1,414) or confounders (n =150). The final sample consisted of 7,175 participants (***Appendix***, **p2**).

Intrinsic capacity

We adapted the method suggested by Beard et al. (2019).[6] We assessed the five original domains (cognitive, psychological, sensory, locomotor, and vitality) proposed for the IC construct using self-reported measures and physical performance tests as follows:

(1) Cognitive: Cognition was assessed using a battery composed of the following tests: a) temporal orientation, b) delayed recall of 10 common words (episodic memory), c) semantic memory questionnaire (based on four questions about general knowledge), and d) semantic verbal fluency task (executive functioning, vocabular size, and lexical access speed).[12]

(2) Psychological: Depressive symptoms were evaluated using the 8-item Center for Epidemiological Studies-Depression (CES-D) scale.[13] We also obtained information on sleep quality, a distinguished contributor to mental health, using two questions[14]: a) "How would you evaluate the quality of your sleep?" (Possible answers: "excellent", "good", "fair", "poor", or "very poor);" and b) "During the last month, have you taken any sleeping pill?" (Possible answers: "no", "less than once a week", "between 1 and 2 times a week", or "3 or more times a week".

(3) Sensory: To assess vision acuity, participants were asked the following questions: "How good is your eyesight (even when using glasses or contact lenses) for seeing things at a distance, like recognizing a friend across the street?" and "How good is your

eyesight (even when using glasses or contact lenses) for seeing things up close like reading ordinary newspaper print?".[15,16] The question used to assess hearing acuity was "How do you evaluate your hearing (even when using a hearing device)?". Participants answered "excellent", "good", "fair", "poor", or "very poor" to these questions.

(4) Locomotor: Gait speed and balance tests were used to estimate lower limb physical functionality. Gait speed was calculated by measuring the time to walk three meters at the usual pace with or without assistive devices and the mean of two attempts was considered.[12] The balance test from the Short Physical Performance Battery was applied.[17]

(5) Vitality: This domain integrated broader underlying determinants such as strength, nutrition, and energy.[6] The handgrip strength of the dominant hand was evaluated using a Saehan handheld dynamometer and the mean of three measurements was computed.[18] Nutritional status considered the report of unintentional weight loss ≥3 kg during the last three months.[19] We assessed lack of energy by asking participants two questions regarding the past week:[20] a) exhaustion: "How often did you feel that you could not carry things forward?"; and b) poor endurance: "How often did the routine activities require a major effort to be completed?".

Detailed information on variables (format and scoring) composing the intrinsic capacity domains can be seen in the supplement (***Appendix***, **p3**).

Outcomes

Our primary outcomes were functional ability measured through validated instruments assessing ADL and IADL. ADL were evaluated using the Katz index,[21] which ranks the ability of individuals to perform six self-care tasks, namely eating, transferring, continence, toileting, dressing, and bathing. IADL were assessed using the Lawton scale,[22] which incorporates eight activities essential to living independently in the community, namely using the telephone, preparing food, doing laundry, housekeeping, taking medications, handling finances, shopping, and using transportation. For each activity, participants reported whether they could perform it by themselves — with or without difficulty — or needed help from another person. Because the IC construct was proposed to measure preserved functions, not losses, we applied the same rationale to the outcome measures and focused on the conserved ability to perform activities of daily living. Therefore, we classified people with preserved ADL or IADL if they reported executing ADL or IADL without any difficulty and help from another person, respectively.[23]

We also retrieved information on AADL by grouping participation and leisure-time activities on a 14-point scale (***Appendix***, **p4**). AADL included the following: social contacts, traveling, going to public places, manual activities, using the computer, driving, volunteer work, care or assistance to other people, and participation in social organizations.[24] These volitional and more sophisticated tasks help people build and maintain relationships, participate and contribute to society, promoting and maintaining their sense of agency and self-identity. For statistical analysis, we defined high performance in AADL as scores in the highest quartile.

Other measurements

We registered information on sociodemographic factors, chronic diseases, and modifiable risk factors as possible confounders.[6] Sociodemographic factors included age, sex, race/ethnicity,[12] education, marital status, and residence in urban or rural area. Prevalent chronic diseases in older adults, including hypertension, diabetes, cancer, lung disease, heart failure, stroke, and osteoarthritis, were assessed by asking individuals if a physician had ever told them that they had such a condition. We also evaluated modifiable risk factors using self-reported information about smoking status and alcohol consumption. We defined binge drinking as alcohol consumption ≥5 doses for males or ≥4 doses for females on a single occasion during the past month.[12]

Statistical analysis

We used confirmatory factorial analysis to operationalize a composite IC measure directly from the items.[6] We conducted a bi-factorial analysis that generated five IC domains and a composite IC measure. To verify the appropriateness of the bi-factorial model, we also performed the 1-factor, 5-factor, and 2-order factor models. We performed confirmatory factor analysis using weighted least squares means and variance adjusted (WLSMV). WLSMV analysis can produce accurate test statistics, parameters estimate and errors, and performs accurately even in the presence of variables with floor or ceiling effects.[25] Finally, we extracted the standardized estimated scores (z-scores) for the composite IC and its five domains. For domains having a negative correlation with the composite IC measure, we multiplied the z-scores by -1. Therefore, a z-score of +1 indicated that the participant's performance was one standard deviation above the sample mean in the respective IC measure.

We checked whether the IC followed a normal distribution by visual inspection with a histogram and we reported reference intervals for the total sample and relevant subgroups. We described the participants' characteristics according to IC quartiles, using absolute and relative frequencies for categorical variables and mean and standard deviation (SD) or median and interquartile

range (IQR) for interval variables. We examined differences in the participants' characteristics across the four IC groups using the chi-squared test for categorical variables and one-way ANOVA (normal distributed) or Kruskal-Wallis test (non-normal distributed) for continuous variables. We also computed the Pearson's correlation coefficient between IC and age to explore the relationship between these measures.

We explored the associations of IC and its five domains with the preserved ability to perform ADL and IADL using logistic regression models. We fitted unadjusted and adjusted models to investigate the association of IC and preserved ability in ADL or IADL. Adjusted models considered sociodemographic factors, chronic diseases, and modifiable risk factors. We also tested for the associations of IC and its five domains with high performance in AADL using the same logistic regression models. Finally, we explored whether sociodemographic factors (i.e., age, sex, race/ethnicity, and education level) modified the associations between IC and preserved ability in ADL or IADL, stratifying the analysis in case the interaction term achieved significance.

To investigate the robustness of our findings, we undertook sensitivity analyses. First, we examined the relationships between IC and ability to perform ADL, IADL, and AADL, having the ordinal scores of the functional scales as dependent variables. Second, we investigated the associations of IC with the ability to perform ADL or IADL independently, that is, without help from another person. Third, we removed 'continence' from the Katz index (ADL) and 'doing laundry, housekeeping, preparing food' from the Lawton scale (IADL), as dependence in these activities might reflect gender-specific health conditions or sociocultural aspects, but not functional performance. Fourth, we explored associations of IC with preserved ability in each ADL and IADL. Fifth, we tested the associations of IC and its domains with ADL, IADL, and AADL after stratifying the sample based on age groups (<65 and ≥65 years old), as functional impairment may have different meanings and impacts in midlife compared to late-life.[2] Lastly, we checked a linear trend on the association between IC and preserved ability in ADL, IADL, and high performance in AADL using quartiles of IC as the variable of interest.

We used sampling weights to adjust for complex survey design from ELSI-Brazil.[11] Tests were two-tailed and considered alpha level<0.05. Analyses were performed using Stata software version 17 (StataCorp, College Station, TX, USA).

Role of the funding source

The funding agencies had no role in the design or conduct of the study, data collection, data analysis, data interpretation, and preparing, reviewing, or approving the manuscript.

Results

Participants had a mean (SD) age of 62·4 (9·3) years (range=50-105 years), 53% were female, 41% were white, and 61% had <8 years of formal education (Table 1). Regarding activities of daily living, 82% of participants reported preserved ADL and 56% preserved IADL. Compared to participants, those excluded from this study due to incomplete data tended to be older and have a higher prevalence of disability (***Appendix*, p5**).

The bi-factorial model revealed satisfactory robust goodness-of-fit indices (Chi-squared test =239·9, p<0·001, Comparative Fit Index [CFI]=0·984, Root-Mean-Square Error of Approximation [RMSEA]=0·020, Standardized Root Mean Square Residual [SRMR] =0·015). Of note, the bi-factorial showed appropriateness compared to other factor models (***Appendix*, p6**). All factorial loadings were significant within their respective domains and to the IC composite measure (Figure 1), with the exceptions of a) the variables of vitality domain loaded only on the IC composite measure, and b) balance test (from mobility domain) and poor endurance (from vitality domain) did not load on the IC composite measure. The IC composite z-score ranged from -3·07 to 3·87 in the sample. We showed detailed information on the IC composite z-score distribution — for the total sample (histogram) and relevant subgroups (reference intervals) — in the ***Appendix*, p7**. There was a small negative correlation between IC and older age (Pearson's correlation coefficient= -0·29, 95% confidence interval= -0·32 to -0·27) (***Appendix*, p8**). Higher levels of IC were associated with preserved ADL and IADL, younger age, male sex, white race, having a partner, living in urban areas, higher education, fewer chronic diseases, and reporting smoking and alcohol consumption (Table 1).

IC and its five domains were independently associated with preserved ADL or IADL (Table 2). We also observed a significant relationship between IC and its five domains with high performance in AADL (Table 2). We did not find significant interactions between IC and older age, race/ethnicity, or level of education for preserved ability to perform ADL or IADL, respectively. However, sex modified the associations between IC and preserved ability to perform ADL or IADL, with p-values for interaction=0·04 and 0·001, respectively (Figure 2). For all sexes, we observed better functional performance for higher levels of IC (Figure 3). Nevertheless, the relationship between IC and preserved abilities in activities of daily living was stronger among female participants (***Appendix*, p9**).

In sensitivity analyses, we confirmed our findings, emphasizing the importance of IC to functional performance in routine activities. First, the results did not change when we defined the outcomes as (1) ordinal variables representing the score of the ADL, IADL, and AADL scales (***Appendix*, p10**); (2) the ability to independently perform ADL or IADL with or

Characteristics	Total (n = 7,175)	Quartiles of Intrinsic Capacity [a] Q1 (n = 1,794)	Q2 (n = 1,794)	Q3 (n = 1,794)	Q4 (n = 1,793)	*P*-value[b]
Functional measures						
Performance in ADL, n (%)						<0·001
Preserved	5804 (81·7)	1242 (69·4)	1450 (80·8)	1523 (84·9)	1589 (88·6)	
Execute with difficulty	849 (10·0)	339 (18·9)	224 (12·5)	154 (8·6)	132 (7·4)	
Need help from another person	518 (8·3)	209 (11·7)	120 (6·7)	117 (6·5)	72 (4·0)	
Katz index (0-6), median (IQR)	6 (6, 6)	6 (6, 6)	6 (6, 6)	6 (6, 6)	6 (6, 6)	<0·001
Performance in IADL, n (%)						<0·001
Preserved	3791 (56·1)	514 (28·9)	872 (48·9)	1089 (61·2)	1316 (73·8)	
Execute with difficulty	2498 (29·4)	1037 (58·4)	679 (38·1)	468 (26·3)	314 (17·6)	
Need help from another person	833 (14·5)	225 (12·7)	231 (13·0)	223 (12·5)	154 (8·6)	
Lawton index (0-8), median (IQR)	8 (7, 8)	7 (6, 8)	8 (7, 8)	8 (7, 8)	8 (8, 8)	<0·001
AADL index (0-14), median (IQR)	5 (3, 7)	4 (2, 6)	5 (3, 7)	6 (3·5, 8)	7 (5, 9)	<0·001
Sociodemographic factors						
Age (years), mean (SD)	62·4 (9·3)	65·8 (10·1)	63·3 (9·2)	61·7 (8·8)	58·6 (7·2)	<0·001
Female sex, n (%)	3979 (53·1)	1610 (89·7)	1358 (75·7)	855 (47·7)	156 (8·7)	<0·001
Race or ethnicity, n (%)						<0·001
White	2717 (40·9)	568 (31·7)	668 (37·2)	718 (40·0)	763 (42·6)	
Black	670 (9·1)	186 (10·4)	163 (9·1)	159 (8·9)	162 (9·0)	
Mixed	3318 (43·9)	884 (49·3)	832 (46·4)	814 (45·4)	788 (43·9)	
Other	470 (6·1)	156 (8·7)	131 (7·3)	103 (5·7)	80 (4·5)	
Have a partner, n (%)	4337 (60·4)	829 (46·2)	939 (52·3)	1161 (64·7)	1408 (78·5)	<0·001
Living in urban areas, n (%)	6096 (85·0)	1499 (83·6)	1497 (83·4)	1514 (84·4)	1586 (88·5)	<0·001
Education less than 8 years, n (%)	4620 (61·1)	1477 (81·9)	1311 (72·6)	1080 (59·7)	802 (44·3)	<0·001
Chronic diseases						
Hypertension, n (%)	3717 (51·8)	1087 (60·6)	955 (53·2)	867 (48·3)	808 (45·1)	<0·001
Diabetes, n (%)	1105 (15·4)	342 (19·1)	296 (16·5)	246 (13·7)	221 (12·3)	<0·001
Cancer, n (%)	358 (5·0)	91 (5·1)	95 (5·3)	102 (5·7)	70 (3·9)	0·083
Lung disease, n (%)	378 (5·3)	123 (6·9)	114 (6·4)	78 (4·3)	63 (3·5)	<0·001
Heart failure, n (%)	478 (6·7)	167 (9·3)	120 (6·7)	101 (5·6)	90 (5·0)	<0·001
Stroke, n (%)	305 (4·3)	126 (7·0)	82 (4·6)	56 (3·1)	41 (2·3)	<0·001
Osteoarthritis, n (%)	1570 (21·9)	587 (32·7)	465 (25·9)	316 (17·6)	202 (11·3)	<0·001
Modifiable risk factors						
Smoking status, n (%)						<0·001
Never	3236 (45·1)	912 (50·8)	843 (47·0)	801 (44·6)	680 (37·9)	

Table 1 (Continued)

Characteristics	Total (n = 7,175)	Quartiles of Intrinsic Capacity [a]				*P*-value [b]
		Q1 (n = 1,794)	Q2 (n = 1,794)	Q3 (n = 1,794)	Q4 (n = 1,793)	
Former	2692 (37·5)	587 (32·7)	656 (36·6)	678 (37·8)	771 (43·0)	
Current	1247 (17·4)	295 (16·4)	295 (16·4)	315 (17·6)	342 (19·1)	
Binge drinking, n (%)	696 (9·7)	55 (3·1)	93 (5·2)	182 (10·1)	366 (20·4)	<0·001

Table 1: **Characteristics of participants according to quartiles of intrinsic capacity.**
IQR = interquartile range; ADL = activities of daily living; IADL = instrumental activities of daily living; AADL = advanced activities of daily living.
[a] The intrinsic capacity composite score ranged from -3·13 to -0·73 for Q1; -0·73 to -0·09 for Q2; -0·09 to 0·68 for Q3; and 0·68 to 3·95 for Q4 (higher = better performance).
[b] Comparisons investigated differences among the quartiles of intrinsic capacity; we used the chi-squared test for categorical variables and the Kruskal-Wallis test (i.e., Katz index, Lawton index, and AADL index) or one-way ANOVA (i.e., age) for continuous variables.

without difficulty (***Appendix***, **p11**); or (3) removed some activities from the ADL and IADL to avoid the interference of gender-specific health conditions or sociocultural aspects (***Appendix***, **p12**). Second, we noticed that IC was associated with preserved ability to perform each ADL and IADL (***Appendix***, **p13**). Third, we observed similar results for the relationship between IC and functional ability among middle-aged and older adults (***Appendix***, **p14**). Lastly, we found a linear trend in the associations of IC and functional ability in ADL, IADL, and AADL, with higher odds of having better performance as the levels of IC increase (***Appendix***, **p15**).

Discussion

In this nationally representative sample of Brazilian people aged ≥50 years, we used a rigorous psychometric approach to operationalize a composite IC measure. The generated measure of IC proved to be consistently associated with functional performance in various routine activities, encompassing self-care to productive and leisure-time activities. Furthermore, we reported that the strong relationship between IC and functional performance builds on the significant associations of its five domains with preserved ADL or IADL. The same is true when assessing social and relational tasks examined through the AADL. Interestingly, we found that sex modified the association between IC and functional performance in ADL or IADL, having a higher effect among female participants. Altogether, our results demonstrate that the IC domains capture information on health status beyond that contributed by sociodemographic factors and chronic diseases.

The theoretical concept of IC underpinning functional ability in older age is a key element of healthy aging.[3] This new framework emphasizes the positive health attributes and physiological reserve that individuals can develop and maintain across the life course. With this initiative, WHO intends to change stereotypical notions of older age and advance towards the transformation needed to achieve the gains envisioned in the Decade of Healthy Aging.[3,4] The idea is also to disseminate a more integrative approach toward achieving optimal health status, which shifts from the concept of 'chronological' age to 'biological' age, and from a disease-oriented approach to a person-centered approach.[5,8] Our results support this initiative by showing a weak correlation between IC and chronological age. We also observed that IC identified individuals at different levels of functional ability, proving that this measure captures heterogeneity in the older population independently of clinical phenotypes.

Traditional research on 'biological aging' tends to focus on physical and cognitive performance.[6] Nonetheless, IC extrapolates this notion as it also considers psychological, sensory, and vitality capacities that are

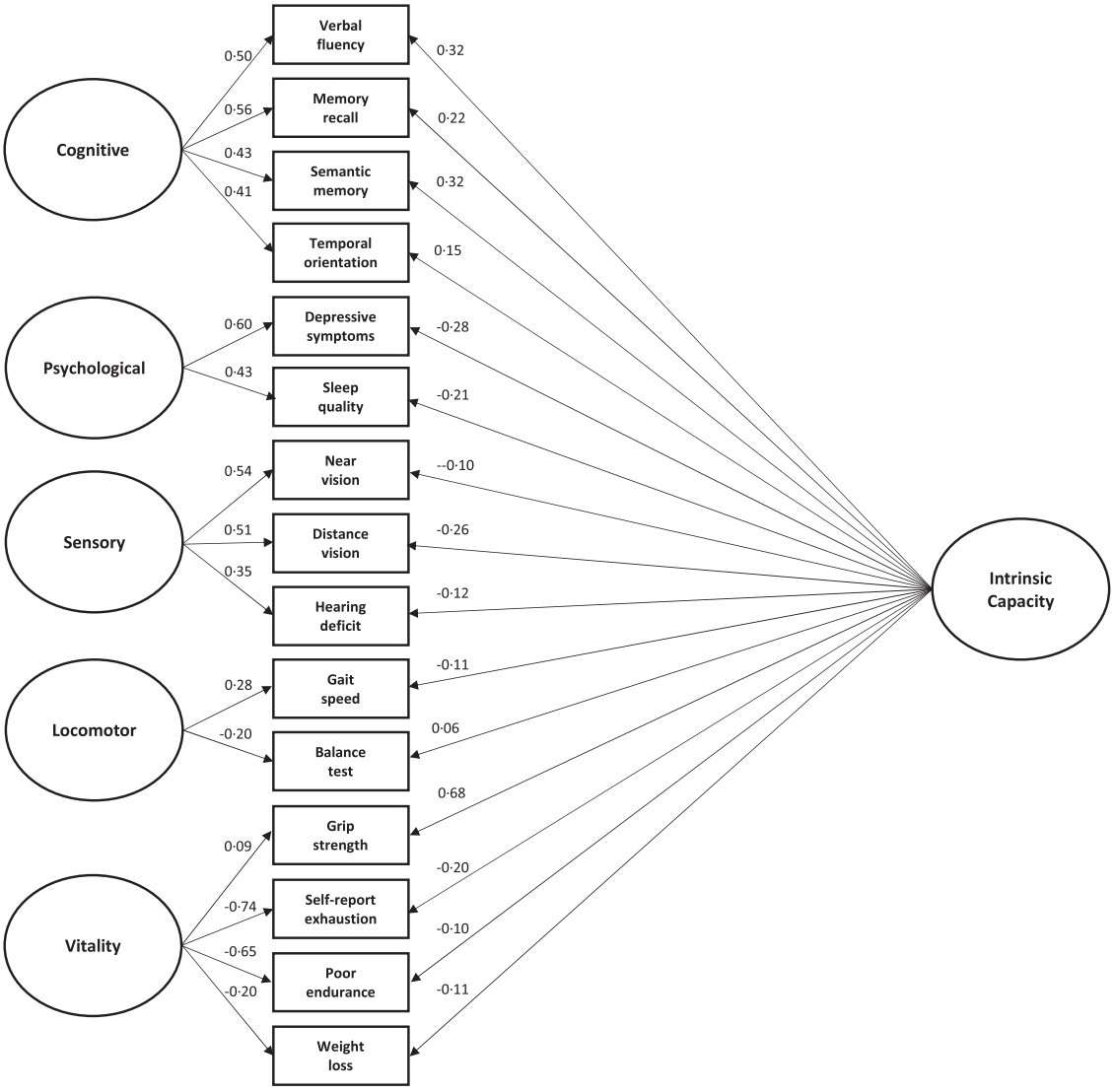

Figure 1. Bi-factor confirmatory factor analysis model of intrinsic capacity.

essential for healthy aging.[2] Our results highlighted that each IC domain potentially captures functional ability not only in ADL and IADL but also in AADL, which involves health-associated dimensions not previously examined in the context of IC, even though leisure activities, entertainment, and social interactions are recognized as essential aspects of healthy aging.[4] We also demonstrated the independent relationship of IC with each ADL and IADL. However, it is worth mentioning that functional ability does not depend only on IC. It results from the balance between people's IC and their environmental demands. [3,26] Thus, we can still maintain functional ability in people with reduced IC by making environmental improvements. For example, grab bars for someone having difficulty in taking a shower or a lift chair for someone unable to transfer.[26] The same is valid for the neighborhoods (e.g., barrier-free and well-maintained sidewalks) and cities (e.g., accessible public transportation).[3] Such environmental improvements can compensate for a reduced IC in some degree, preserve people's independence, and promote healthy aging.[3,26] As IC research continues to grow, investigations on interactions between IC and the environment will provide a fuller picture of functional ability in the context of healthy aging.

For the meantime, our findings might have practical implications in aged care. For example, the consistent associations between IC and a wide range of routine activities show the relevance of stratifying the older population by IC rather than chronological age and comorbidities.[8] Similar to development charts used in pediatric practice, standardized IC composite scores

might guide healthcare professionals and policy makers in identifying those individuals presenting deviations from healthy aging.[6] A new attitude in clinical assessment, which surpasses disease-restricted model of care provision towards a function-based approach focused on the IC integrative measure, can target more closely the needs of older people. Such a positive construct help avoids ageism and may promote person-centered and holistic care in public health actions and clinical practice in our increasingly aging societies.[4]

While the IC framework is up-and-coming, more research is needed to improve its operationalization and measurements before routine implementation in practice. For instance, as a relatively new concept, IC has been conveniently constructed based on available measures collected for distinct purposes, sometimes to detect health deficits (i.e., depressive symptoms, sensory deficits) rather than capacities.[27] The variables to be added to handgrip strength in the vitality domain also remain under extensive debate.[8,27] Previous work focused on biological markers (e.g., forced expiratory volume, hemoglobin, hormone dosage).[6] Nevertheless, WHO has been giving special consideration to anthropometric parameters (e.g., body mass index, weight loss) as proxy measures for nutrition, which strongly impacts age-related changes in energy metabolism, hindering homeostasis, a core element of the vitality domain.[27] Aligned with these principles, we combined practical information on weight loss and lack of energy with handgrip strength to compose the vitality domain. Our results showed the close relationship between vitality and performance in ADL, IADL, and AADL. A practical strategy to measure vitality might also facilitate the routine comprehensive assessment of older adults, a crucial aspect for LMICs, and raise awareness about potentially reversible conditions affecting healthy aging.[27]

It is noteworthy that we did not find that age, race/ethnicity, and formal education modify the relationship between IC and functional ability. However, we observed significant sexes differences for the IC construct. Whilst male participants presented higher mean IC scores, females had a stronger relationship between IC and functional ability. Sex and gender-related factors impacting functionality offer potential explanations on how females and those who identify as women are more likely to be susceptible to the health dimensions detected by IC.[28,29] During adulthood, males have higher baseline muscle mass, strength, and endurance due to hormonal factors (e.g., testosterone), while females tend to exhibit greater fat mass and muscle fat infiltration. Altogether, these characteristics can lead to biomechanical and body composition disadvantages in females, indicating that even minor differences in IC scores might significantly influence their functional abilities.[28,29] Females are also more likely to report higher perceptions of functional limitations.[28] Additionally, women more often assume or are required to care

	Odds ratio (95% confidence interval)					
	Preserved ADL		Preserved IADL		High performance in AADL	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
Intrinsic capacity	1·71 (1·55–1·89)	1·72 (1·54–1·93)	2·19 (2·02–2·38)	1·95 (1·77–2·16)	2·00 (1·83–2·19)	1·79 (1·59–2·00)
Specific capacities						
Cognitive	1·26 (1·16–1·36)	1·17 (1·06–1·28)	1·55 (1·42–1·68)	1·31 (1·19–1·43)	2·50 (2·25–2·77)	1·73 (1·59–1·87)
Psychological	2·08 (1·94–2·22)	1·96 (1·84–2·09)	1·96 (1·83–2·10)	1·89 (1·76–2·04)	1·32 (1·23–1·42)	1·17 (1·07–1·29)
Sensory	2·03 (1·88–2·19)	1·88 (1·75–2·02)	2·07 (1·94–2·21)	1·90 (1·77–2·04)	1·81 (1·67–1·95)	1·42 (1·31–1·54)
Locomotor	1·73 (1·55–1·92)	1·71 (1·52–1·93)	1·99 (1·80–2·20)	1·77 (1·56–2·01)	2·62 (2·32–2·96)	1·78 (1·59–1·99)
Vitality	1·90 (1·77–2·04)	1·81 (1·69–1·94)	1·81 (1·69–1·95)	1·80 (1·67–1·95)	1·19 (1·11–1·27)	1·10 (1·01–1·20)

Table 2: **Associations of intrinsic capacity and its five domains with performance in basic, instrumental, and advanced activities of daily living (n = 7175).**
ADL = activities of daily living; IADL = instrumental activities of daily living; AADL = advanced activities of daily living;
Estimates were calculated using logistic regression models for preserved ability in ADL or IADL and high performance in AADL. The score of intrinsic capacity and its five domains were standardized (z-score). High performance in AADL was defined for those having > 7 points on a 14-point AADL scale.[24] Adjusted analyses included age, sex, race/ethnicity, education, marital status, place of residence (urban or rural area), comorbidities (hypertension, diabetes, cancer, lung disease, heart failure, stroke, and osteoarthritis), smoking status, and binge drinking.

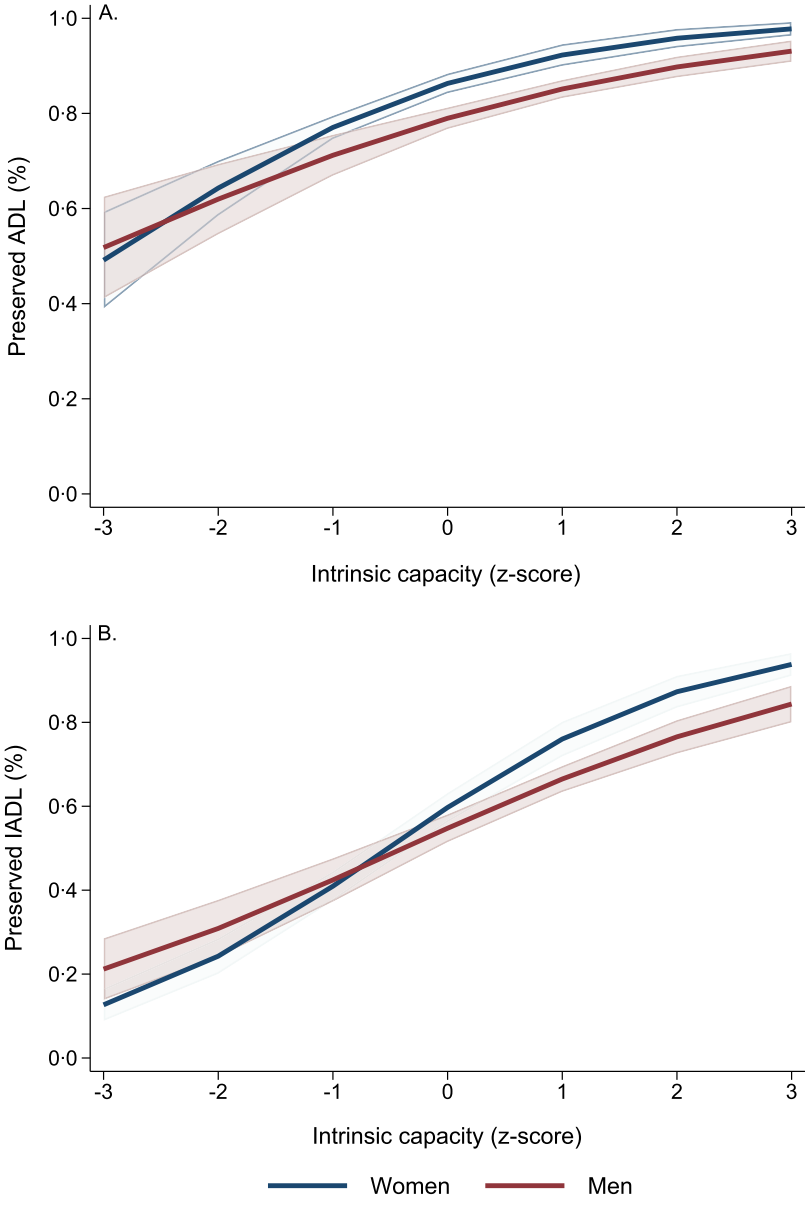

Figure 2. Interaction of sex and intrinsic capacity on preserved functional ability in routine activities among people aged 50 years and older (n = 7,175). (**A**) Activities of daily living (ADL); **(B)** Instrumental activities of daily living (IADL).

Preserved ADL (i.e., bathing, dressing, toileting, transferring, continence, and eating) and preserved IADL (i.e., handling finances, taking medications, using transportation, doing laundry, housekeeping, preparing food, shopping, and using the telephone) were defined for those doing the activities without difficulty or need for help from another person.

P for interaction between intrinsic capacity and sex for preserved ability in ADL = 0·04.

P for interaction between intrinsic capacity and sex for preserved ability in IADL = 0·001.

for family members, but they have less assistive support and resources available to their functional needs. Nevertheless, all these hypotheses remain somewhat speculative, and further research is needed to elucidate this topic.[29]

Our study had notable strengths. Like other Latin American countries, Brazil faces an accelerated population aging, with a large number of people experiencing considerable disadvantages (e.g., socioeconomic problems, more prevalent age-related impairments) as they get older.[9] We were able to show that sociodemographic determinants did not modify how IC expresses the functional ability of individuals. In addition, our analyses included social and relational tasks encompassed by the AADL, which are essential to understanding healthy aging. While our findings are promising, they should

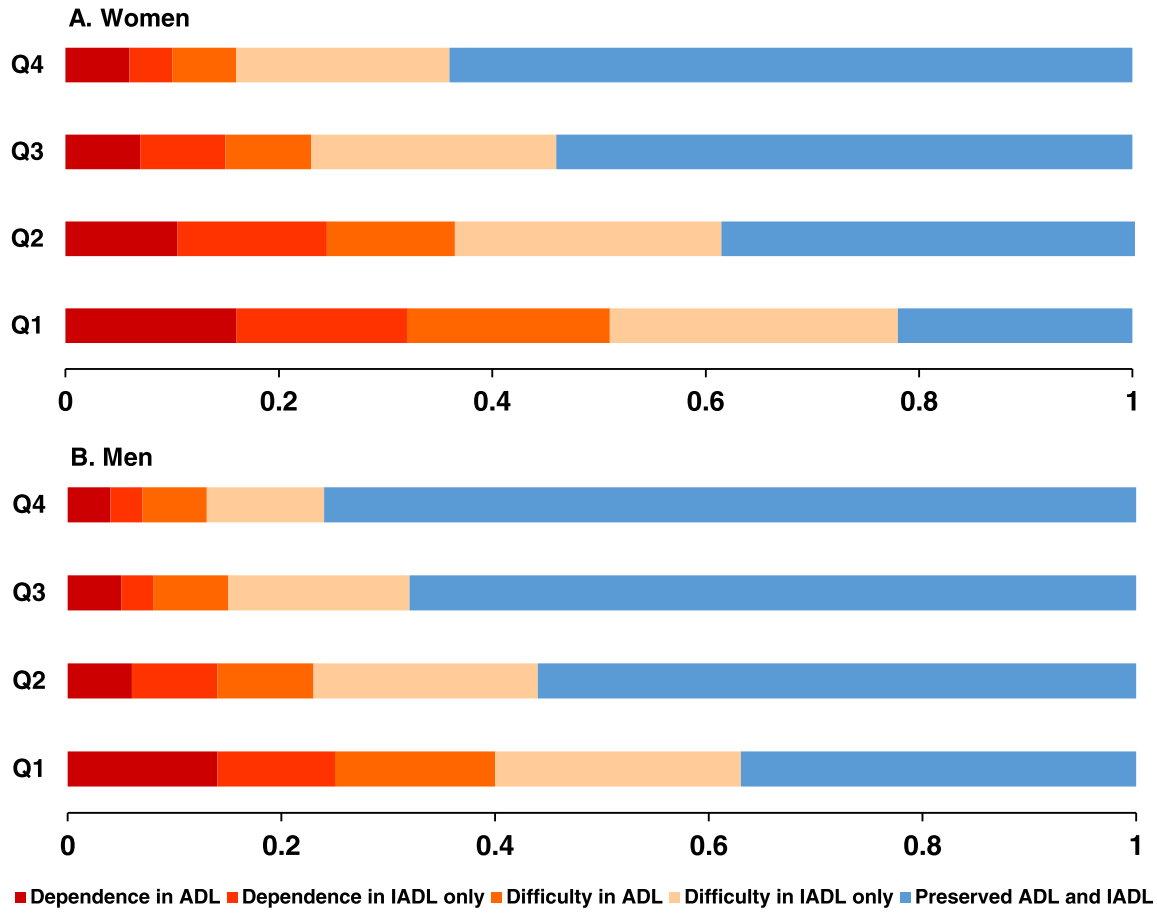

Figure 3. Prevalence of ability to perform ADL and IADL with or without functional impairment according to quartiles of intrinsic capacity stratified by sex. (A) Female participants, n = 3,979; **(B)** Male participants, n = 3,196.

Comparisons investigating differences among the quartiles of intrinsic capacity showed a p-value <0·001 for female and male participants.

be interpreted in light of their limitations. First, our results support previous work by demonstrating the appropriateness of the bi-factorial model to construct the IC composite measure. However, the lower item loading at the general IC factor might be occurring due to residual variance among the items, which can contribute to some degree of imprecision in the IC construct. In addition, as the 1-factor and 5-factor models also revealed satisfactory goodness-of-fit indices, more research is needed before determining the best factor model for the IC measure. Second, although we assessed comprehensive information to construct the IC domains, we could not include some biological biomarkers (i.e., hormonal measurements, forced expiratory volume) that might contribute to the vitality domain.[6] Moreover, questions in the sensory domain considered the use of devices (i.e., glasses, hearing aids). Even though this is common in similar large population-based cohort studies on aging,[6,8] it incorporated external adaptations into the IC measure. Third, we acknowledge that the study participants differed from those who were excluded, which might have introduced bias to our results. Nonetheless, the losses due to severe disability would have probably underestimated the relationship between IC and functional ability. Fourth, we could not test within and between individual changes over time because of our cross-sectional study design, precluding temporal or causal inferences.[7] Likewise, the characteristics associated with IC in the unadjusted analyses should be interpreted with caution. For example, previous findings linking smoking and alcohol consumption to health status in older adults suggested the occurrence of survival bias and reverse causality, mainly when using a cross-sectional design.[30] Future investigations evaluating longitudinal trajectories of IC among older Brazilians, including comparisons with other populations, are expected once information on new waves of the ELSI-Brazil becomes available.

In conclusion, our findings based on a multicultural population of individuals aged ≥50 years from Latin

America provided robust evidence for the validity and reliability of the IC construct to measure healthy aging. The application of this novel concept represents a unique opportunity for disseminating function-based assessments and integrated care of older people living in diverse settings and with different health conditions. Future studies should investigate whether incorporating the IC into practice improves health outcomes for older individuals and societies.

Contributors

MJRA and LB: conceptualization, data curation, investigation, formal analysis, methodology, visualization, writing – original draft, and writing – review & editing.

CKS: conceptualization, investigation, methodology, project administration, supervision, writing – original draft, and writing – review & editing.

CS, DO, RDP: conceptualization, methodology, writing – original draft, and writing – review & editing.

MC, MRP, and CPF: conceptualization, methodology, and writing – review & editing.

FBA and MFLC: funding acquisition, methodology, and writing – review & editing.

Data sharing

The Brazilian Longitudinal Study of Aging (ELSI-Brazil) data are freely available to researchers upon registration with the ELSI-Brazil project at the following address https://elsi.cpqrr.fiocruz.br/en/register/.

Declaration of interests

The authors have no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lana.2022.100284.

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