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Original Article

Comparison of robustness, resilience and intrinsic capacity including prediction of long-term adverse health outcomes: The KORA-Age study

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ABSTRACT

Background: Frailty, resilience and intrinsic capacity (IC) are concepts to evaluate older person`s health status, but no comparison of their associations with adverse health outcomes exists. We therefore aimed to assess which concept is most useful for determining long-term health of older adults.
Methods: Analyses were based on the KORA (Cooperative Health Research in the Region of Augsburg)-Age study (n = 940, 65–93 years). Frailty was evaluated using the physical frailty-phenotype by Fried et al. For comparability to resilience and IC, we chose the protective concept of robustness instead of frailty in the present analysis. Resilience was measured by the 11-item resilience-scale. The IC-score was based on 4 domains (locomotion, cognition, vitality and psychiatric capacities). Associations with falls, disability, and hospitalization at 3-year and 7-year follow-up and with mortality were evaluated by multivariable adjusted logistic and Cox regression. Concept overlaps were illustrated by a Venn-diagram.
Results: In the fully adjusted models, robustness showed significant inverse associations with most outcomes (3-year follow-up: OR (95%CI): disability 0.448 (0.300−0.668), 7-year follow-up: falls 0.477 (0.298−0.764), hospitalization 0.547 (0.349−0.856), and all-cause mortality 0.649 (0.460−0.915)) while resilience and IC showed significant inverse associations with disability only (e.g., 7-year-follow-up: resilience: 0.467 (0.304 −0.716), IC: 0.510 (0.329−0.793)). 23% of the participants met the criteria for both robustness and IC while 22% met those for robustness and resilience.
Conclusion: Robustness was the most useful concept, showing the strongest protective associations for most adverse health outcomes. IC and resilience showed their main strengths in capturing protective associations for disabilities. Robustness overlapped with resilience and IC, supporting the concept of mind-body-interaction.
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1. Introduction

Especially among older people there is a high heterogeneity regarding preserved physical and mental functions [1]. To capture and evaluate these functions and identify potential treatment targets, three concepts – frailty, resilience, and intrinsic capacity (IC) – have been developed over time. Resilience and IC are ability-focused whereas frailty is either considered as a phenotype caused by a decreased physiologic reserve and multiple physiological dysregulations [2] or an accumulation of deficits [3].

Frailty is the oldest and therefore best established concept and is even recognized as a “geriatric syndrome” [2]. There are two main approaches that aim to identify the origin of frailty [3,4]. Fried et al. described the “physical phenotype of frailty” in which frailty is understood as a syndrome comprising all consequences of dysregulations in multiple regulatory systems [4]. The approach by Rockwood and Mitnitski

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describes the frailty state based on an accumulation of deficits [3] which not only include physical capacities but also mental and social aspects. Frailty is therefore measured using a high number of items (>30) including diseases, geriatric syndromes, functional disabilities and other limitations [5].

The term “resilience” was originally used to describe the elastic properties of materials [6] and was subsequently applied to humans who showed high abilities to “bounce back” successfully when confronted with adverse events [7]. It is therefore a more psychologically-driven concept representing someone`s mental strengths and skills such as coping with misfortune and challenging situations. It is mainly evaluated based on self-assessment questionnaires [8].

Within the context of the Healthy Aging campaign in 2015, the World Health Organization (WHO) introduced IC as a new, competency-based concept. It describes the composite of an individual’s physical and mental capacities [1] but no consensus definition yet exists [9]. In 2019, the WHO proposed measurement protocols for the five major domains (locomotion domain, psychological domain, cognition domain, sensory domain and vitality domain) of IC in the Handbook On The Integrated Care For Older People Guidelines (ICOPE) [10]. However, until now neither a unique measurement tool for total IC nor for each domain have been defined, thus many different tools are in use [11].

Since in daily clinical practice time is a limited resource, instead of measuring all three concepts, it is more reasonable to assess the health status of patients using only one of these concepts. As the main value of each concept is the association with negative health outcomes, we aimed to identify if any of the concepts entails stronger associations with future adverse health outcomes compared to the other concepts. Therefore, a direct comparison of the associations between each of the three concepts with some of the most important negative health outcomes was conducted. Additionally, as overlaps between frailty and IC [12,13] and resilience and IC [13] have been discussed in theory but only the relationship between resilience and frailty has been evaluated in a population-based cohort before [14], we further directly compared the frequencies and overlaps between the three concepts within a large epidemiologic cohort of community-dwelling geriatric participants comprising two follow-up examinations after three and seven years.

2. Material and methods

2.1. Study population and data collection

The data in this analysis was derived from the KORA-Age study which is a follow-up study including older participants (65–93 years) from the population-based MONICA (MOnitoring of Trends and Determinants in CArdiovascular Disease) and KORA-studies [15]. Further information about the study`s design, sampling method, and data collection have been reported elsewhere [16,17]. In brief, the KORA-Age cohort consists of all participants from the four surveys of the MONICA/KORA-study conducted in 1984–2001 in the area of Augsburg, Southern Germany, born in 1943 or before and still alive during the primary KORA-Age survey in 2008 (n = 4127) [16]. Initial recruitment was based on data of the resident`s registration office, stratified by urban- and countryside-population, sex and 10-year age categories. Inclusion criteria were German nationality and primary residency within the study region. 1079 participants completed the KORA-Age baseline survey and an additional physical examination in 2009. Follow-ups were conducted in 2012 (n = 882) and 2016 (n = 567) [17].

2.2. Outcome measures

Socio-demographic characteristics and lifestyle behavior were evaluated during a personal or telephone interview. To assess the history of falls, the NHANES-questionnaire (National Health and Nutrition Examination Survey) [18] was used including the questions “Did you fall in the previous year?” with possible answers “yes, once”, “yes, more than once” and “no” which were dichotomized into “at least one fall” and “no falls”. Hospitalization was assessed using the question “In the last 12 months, have you been hospitalized at all?” with two answering possibilities (“yes” or “no”). Disability status was assessed using the Health Assessment Questionnaire–Disability Index (HAQ-DI) [19], which includes 20 items in eight categories of daily living. Each response was scored with a four-point scale with higher scores indicating more disability. The highest scores within each category were summed up (0–24) and then divided by eight which led to the final continuous disability-score (0–3). According to Krishnan et al. [20] the presence of disability was defined as HAQ-DI > 0. The variable was therefore dichotomized in “presence of disability” (HAQ-DI > 0) and “no disability” (HAQ-DI = 0). All participants were followed for all-cause mortality using official death certificates until October 7th 2016.

2.3. Robustness

In order to enhance the comparability of frailty with the two protective concepts resilience and IC, we used the protective form of frailty, namely “robustness”. Robustness was defined as the absence of frailty or pre-frailty. Participants who scored 0 points in the frailty assessment were classified as being robust, participants who scored ≥ 1 point were classified as frail [21]. Robustness status was defined based on a 5-item frailty phenotype scale as proposed by Fried et al. [4]. The criteria were slightly adapted due to data availability [22].

1. Exhaustion: The criterion was met when participants replied “never” to the statement “I felt energetic and active in the last two weeks”.
2. Physical inactivity: Participants who reported neither walking > 30 min on working days nor performing any sports met the criterion.
3. Weakness: Handgrip strength was reported as the mean value of three measurements of the dominant hand using the JAMAR handheld dynamometer (Saehan Corp., Masan, Korea). Participants within the lowest quintile, stratified by sex and body mass index (BMI) quartiles, met the criterion.
4. Weight loss: Participants who reported a loss of weight > 5 kg within the last past 6 months met the criterion.
5. Low locomotion: The Timed-up and Go-test (TUG) was performed in all participants. Participants in the highest quintile stratified according to sex and mean standing height met the criterion.

2.4. Resilience

Resilience was measured using the German version of the 11-item resilience-scale [23]. Across all eleven questions, values from 1 (= strongly disagree) to 7 (= strongly agree) were added up to a score ranging from 11 to 77 with higher scores representing higher resilience. Participants in the upper third were categorized as being resilient [24].

2.5. Intrinsic capacity

Due to the lack of a consensus definition and a standardized measurement tool for IC, we designed an IC-score (Table 1) according to the domains suggested in the Integrated Care for older people (ICOPE)-Guidelines by the WHO in 2017 [25] and the IC-score suggested by Lopez-Ortíz et al. [26]. Since no suitable data for the evaluation of the sensory domain were available, we decided to omit this domain which is in line with previous studies [27].

1. Locomotion domain: According to recommendations by the locomotor capacity working group of the WHO, the Timed-Up and Go-test (TUG) was chosen to evaluate the locomotion domain [28]. The TUG was measured continuously in seconds [s] as the time a participant needed to stand up from a chair, walk three meters, turn, walk back to the chair and sit back down [29]. According to the

Table 1
Design of the intrinsic capacity-score (IC-Score).

Locomotion domain: Timed-Up and Go-test	
<12 s	1
≥12 s	0
Psychological domain: GDS-15	
No depression (Score < 5)	1
Depression (Score ≥ 5)	0
Cognition: TICS-M-Score	
No impairment (Score ≥ 32)	1
Impairment (Score < 32)	0
Vitality: SCREEN II-questionnaire	
No risk (Score ≥ 41)	1
At risk (Score < 41)	0

GDS-15: 15-item Geriatric Depression Scale; SCREEN II: German version of the Seniors in the community: risk evaluation for eating and nutrition, Version II; TICS-M: modified German version of the telephone interview for cognitive status.

meta-analysis by Lusardi et al. of community-dwelling cohorts, a cut-off of 12 s was chosen [30].

2 Psychological domain: The psychological domain was measured using the 15-item Geriatric Depression Scale (GDS-15) [31]. In order to detect any form of depression, we used, in line with prior studies, a cut-off of 5 to dichotomize the scale into depression (score > 5) and no-depression (score ≤ 5) [31,32]. The criterion was met when the participant scored ≤ 5 points and therefore no depression could be suspected.
3 Cognition domain: Cognition was evaluated using the modified German version of the telephone interview for cognitive status (TICS-M)-Score [33] and dichotomized into possible impairment vs. no-impairment by a point score </≥ 32, respectively, in adaption to the three grade classification by Knopman et al. (≤ 27 possible dementia, 28–31 possible MCI (mild cognitive impairment), ≥ 32 normal cognition [34]). Since only participants without an indication for dementia or mild cognitive impairment should meet the criterion, the cut-off was set to ≥ 32 points.
4 Vitality domain: Vitality was measured by the German version of the Seniors in the community: risk evaluation for eating and nutrition, Version II (SCREEN II)-questionnaire [35] which was also dichotomized into “at risk” vs. “not at risk” by a point score </≥41, respectively, [35], from the original three stage classification (low-risk for malnutrition: 41–48/moderate-risk: 36-<41/high-risk: < 36). The criterion was met when a low risk for malnutrition was present, i.e., ≥ 41 points were reached.

Participants with a score of 4 points were classified as having a high IC whereas a score <4 points indicated low IC.

A comparison of the included items between the concepts can be found within the supplemental material (eTable 1 in the Supplement).

2.6. Covariables

Socio-demographic covariables included age, sex, marital status, and years of education (e.g., school education, apprenticeship, undergraduate/graduate studies) [in years]. For marital status, participants were asked whether they were single/unmarried and living alone, single/unmarried but living with a partner, married and living with a partner, married and living alone, divorced or widowed. Regardless of being married or not, participants who lived with a partner or not were combined into one category (i.e., living with a partner vs. not living with a partner).

Lifestyle factors such as daily amount of alcohol-consumption [g/d] [36], smoking-status and physical activity were assessed during the telephone interview or measured during the in-person examination. The participants who reported smoking regularly or occasionally were classified as current smokers whereas those who quitted were reported as “former” smokers (>100 cigarettes in life) and the ones who smoked ≤100 cigarettes in life as “never” smokers. Physical activity was evaluated using the Physical Activity Scale for the Elderly (PASE), from which continuous physical activity scores were calculated [37]. BMI was calculated as weight in kilogram divided by height in meters squared. Height and weight were measured at the study center.

Further covariables covered the multimorbidity status as defined in the KORA-Age study by Kirchberger et al. [38] based on 10 disease categories from the Charlson Comorbidity Index [asthma/emphysema/chronic bronchitis, arthritis/rheumatism, cancer diagnosed in the past 3 years, diabetes, digestive problems (such as ulcer, colitis, or gallbladder disease), heart problems (such as angina, congestive heart failure, or coronary artery disease), kidney disease, liver problems (such as cirrhosis), stroke, HIV illness/AIDS] [39] and five additional disease categories [neurologic disease (such as multiple sclerosis, Parkinson`s disease, epilepsy), eye disease (such as glaucoma, cataract, macular degeneration, diabetic retinopathy, or retinitis pigmentosa), hypertension, depression, anxiety]. According to Kirchberger et al. [38] subgroups were defined as no disease, one disease or two or more diseases.

In addition, the number of prescribed medications was assessed [15] and used as a covariable.

2.7. Statistical analyses

Descriptive statistics for continuous and categorical variables were expressed as mean and standard deviation or numbers/percentages, respectively. Baseline characteristics of the participants were presented for the total study population and stratified by robustness-, resilience- and IC-status.

After adjustment for potential confounders the associations of robustness, resilience and IC with falls within the last 12 months, disability, and hospitalization within the last 12 months at the 3-year and 7-year follow-up were analyzed using logistic regression analysis and presented as Odds Ratios with 95%-confidence intervals. Included covariables were added in Models 1–3 as follows:

- Model 1: Age, sex
- Model 2: Age, sex + BMI, daily alcohol consumption, marital status, years of education, physical activity measured by the PASE-Score
- Model 3: Age, sex, BMI, daily alcohol consumption, marital status, years of education, physical activity measured by the PASE-Score + multimorbidity according to Kirchberger et al. [38] and count of regular medication.

The associations of the exposures with all-cause mortality during the 7-year follow-up period were analyzed using Cox proportional hazards regression. Results were presented as Hazard Ratios with 95%-confidence intervals. The model adjustment in the Cox regression was the same as in the logistic regression as detailed above. The proportional hazards assumption was checked for all Cox proportional hazards regression models using scaled Schoenfeld residuals. There were no violations of the assumption.

To depict the prevalence and overlap of participants meeting the criteria for robustness, resilience and IC, a Venn-diagram was created using the open-source “eulerr diagram-generator” (https://eulerr.co/).

Overall, significance was assumed when $p \leq 0.05$. All analyses were performed using SPSS version 29.

2.8. Ethics statement

All participants gave written informed consent before their inclusion in the study. In cases where the participant was unable to make an informed decision, consent was received from the participant`s caregiver. Approval from the ethics committee of the Bavarian Medical Association was obtained (reference number 08064).

Table 2
Baseline characteristics.

Characteristics[a]	Total	Robust	Resilient	High intrinsic capacity
n [%]	940 [100]	565 [60]	293 [31]	247 [26]
Age [years]	75 [6]	73 [6]	75 [6]	73 [6]
Female n [%]	463 [49]	279 [49]	134 [46]	105 [43]
Body mass index [kg/m^2]	28.4 [4.3]	27.9 [3.8]	28.3 [3.9]	27.7 [3.5]
Comorbidities [%]				
No comorbidities	89 [10]	73 [13]	45 [15]	38 [15]
One comorbidity	245 [26]	185 [33]	96 [33]	83 [34]
Two or more comorbidities	606 [64]	307 [54]	152 [52]	126 [51]
No. of regularly used prescribed medications	4 [3]	3 [2]	3 [2]	3 [2]
Education [years]	11 [3]	11 [3]	11 [3]	11 [3]
Marital status *n* [%]				
Single or married living alone	50 [5]	31 [6]	12 [4]	6 [2]
Single or married living with a partner	598 [64]	390 [69]	195 [67]	204 [83]
Divorced	47 [5]	26 [4]	15 [5]	4 [2]
Widowed	245 [26]	118 [21]	71 [24]	33 [13]
Alcohol consumption [g/d]	13.3 [17.7]	14.0 [17.9]	12.3 [16.9]	14.3 [18.3]
Smoking n [%]				
Current	44 [5]	26 [4]	7 [3]	5 [2]
Former	365 [39]	206 [37]	124 [42]	97 [39]
Never	531 [56]	333 [59]	162 [55]	145 [59]

[a] Continuous variables are presented as mean ± standard deviation and categorial variables as total number and frequency.

3. Results

3.1. Study population characteristics

Table 2 shows the baseline characteristics of the study cohort. After exclusion of participants with missing values in the exposures and/or covariables out of the baseline KORA-Age-Study population ($n = 1079$) a total of 940 participants were included in the cross-sectional analysis. Baseline characteristics of the total study population and stratified for the concepts robustness, resilience and IC are presented in Table 2. Study participants were on average 75 ± 6 years of age with women representing approximately 50% of the study population. Mean body mass index (BMI) was 28.4 ± 4.3 kg/m^2. At baseline, the majority of participants had two or more comorbidities [64%] and regularly took on average 4 ± 3 prescribed medications per day. The largest proportion of participants [64%] reported living with a partner and most participants [56%] were categorized as "never smokers".

60% [$n = 565$] of the participants met the criteria for robustness and 26% [$n = 247$] met the criteria for IC. 293 out of 940 participants [31%] were identified as having a high level of resilience.

3.2. Associations of robustness, resilience and intrinsic capacity with adverse health outcomes

As presented in Table 3, robustness was associated with the majority of adverse health outcomes. After adjustment for all potential confounders (model 3), we observed a significant inverse association of robustness with falls within the last 12 months (OR (95% CI): 0.477 (0.298−0.764)) and hospitalization within the last 12 months (0.547 (0.349−0.856)) based on the 7-year follow up and with disability (0.448 (0.300−0.668)) based on the 3-year follow-up. No association was found for the hospitalization within the last 12 months based on the 3-year follow up. Based on the 3-year follow-up for falls and the 7-year follow-up for disability significant associations were only found until model 2 (Table 3).

Resilience predominantly showed significant inverse associations with disability (3-year follow-up: 0.550 (0.383−0.789) and 7-year follow-up: 0.467 (0.304−0.716)) after adjustment for all confounders (model 3). Also, based on the 3-year follow-up significant associations with falls were found until model 2.

IC was also significantly inversely associated with disability after adjustment for all potential confounders (Model 3) (3-year follow-up: 0.514 (0.356−0.744) and 7-year follow-up: 0.510 (0.329−0.793)) and showed a significant association with falls based on the 3-year follow-up in model 1

3.3. Associations of robustness, intrinsic capacity and resilience with all-cause mortality

Table 3 also shows the results of the Cox proportional hazards analysis for associations of robustness, IC and resilience with all-cause mortality. Robustness showed a significant inverse association with all-cause mortality after adjustment for all confounders (HR (95% CI): model 3: 0.649 (0.460−0.915)), while IC and resilience showed significant inverse associations in model 1 and 2 only (model 2: resilience: 0.596 (0.413−0.858), IC: 0.575 (0.376−0.878)).

3.4. Prevalence and overlap of robustness, resilience and intrinsic capacity

Fig. 1 illustrates the prevalence and overlap of the participants meeting the criteria for robustness, resilience and IC. 72% met the criteria for at least one of the concepts and 28% of the study population met neither the criteria for robustness, nor for IC or resilience. Among the participants who met the criteria for only one of the concepts, the participants allocated to robustness only represented the largest group (26% of the total study population), followed by those who met the criterium for resilience only (7%). The participants who only met the criterium for high IC-status comprised 2% of the total study population.

The largest overlap between two concepts was identified between participants who met the criteria for IC and for robustness (23%) followed by the ones who met the criteria for resilience and robustness (22%).

Participants who met the criteria for all three concepts represented 10% of the study population.

Table 3
Associations of robustness, resilience and intrinsic capacity with adverse health outcomes and all-cause mortality.

Outcomes Number of events/total number		Robustness	Resilience	Intrinsic capacity
		Odds ratio (95% confidence interval)		
Falls within the last 12 months (3-year follow-up)	Model 1	**0.566 (0.375−0.853)***	**0.609 (0.386−0.962)***	**0.566 (0.342−0.936)***
176/764	Model 2	**0.647 (0.420−0.996)***	**0.626 (0.393−0.996)***	0.621 (0.370−1.042)
	Model 3	0.661 (0.428−1.020)	0.665 (0.414−1.068)	0.648 (0.384−1.092)
Falls within the last 12 months (7-year follow-up)	Model 1	**0.465 (0.299−0.724)***	0.672 (0.427−1.058)	0.695 (0.426−1.135)
119/584	Model 2	**0.437 (0.274−0.698)***	0.653 (0.410−1.039)	0.680 (0.411−1.125)
	Model 3	**0.477 (0.298−0.764)***	0.727 (0.453−1.166)	0.733 (0.440−1.221)
Disability (3-year follow-up)	Model 1	**0.334 (0.229−0.488)***	**0.468 (0.333−0.658)***	**0.398 (0.281−0.564)***
460/753	Model 2	**0.417 (0.282−0.619)***	**0.498 (0.350−0.709)***	**0.477 (0.331−0.685)***
	Model 3	**0.448 (0.300−0.668)***	**0.550 (0.383−0.789)***	**0.514 (0.356−0.744)***
Disability (7-year follow-up)	Model 1	**0.495 (0.312−0.785)***	**0.402 (0.269−0.600)***	**0.416 (0.276−0.625)***
372/583	Model 2	**0.610 (0.373−0.996)***	**0.428 (0.282−0.648)***	**0.482 (0.314−0.741)***
	Model 3	0.703 (0.422−1.169)	**0.467 (0.304−0.716)***	**0.510 (0.329−0.793)***
Hospitalization within the last 12 months (3-year follow-up)	Model 1	0.745 (0.522−1.063)	0.762 (0.531−1.094)	0.756 (0.518−1.105)
197/782	Model 2	0.818 (0.563−1.189)	0.751 (0.520−1.085)	0.811 (0.548−1.200)
	Model 3	0.887 (0.607−1.297)	0.882 (0.604−1.288)	0.904 (0.605−1.350)
Hospitalization within the last 12 months (7-year follow-up)	Model 1	**0.516 (0.340−0.784)***	1.063 (0.712−1.588)	0.828 (0.535−1.282)
140/584	Model 2	**0.526 (0.339−0.817)***	1.083 (0.720−1.630)	0.876 (0.558−1.374)
	Model 3	**0.547 (0.349−0.856)***	1.184 (0.779−1.799)	0.914 (0.578−1.445)
All-cause mortality		Hazard Ratio (95% confidence interval)		
190/940	Model 1	**0.541 (0.394−0.744)***	**0.564 (0.394−0.808)***	**0.542 (0.359−0.820)***
	Model 2	**0.574 (0.409−0.805)***	**0.596 (0.413−0.858)***	**0.575 (0.376−0.878)***
	Model 3	**0.649 (0.460−0.915)***	0.708 (0.485−1.031)	0.673 (0.437−1.038)

Model 1: Age, sex.
Model 2: Model 1 + BMI, alcohol consumption, smoking status, marital status, years of education, physical activity.
Model 3: Model 2 + multimorbidity by Kirchberger, no. of regularly used prescribed medications.
Bold font and *: $p \leq 0.05$.

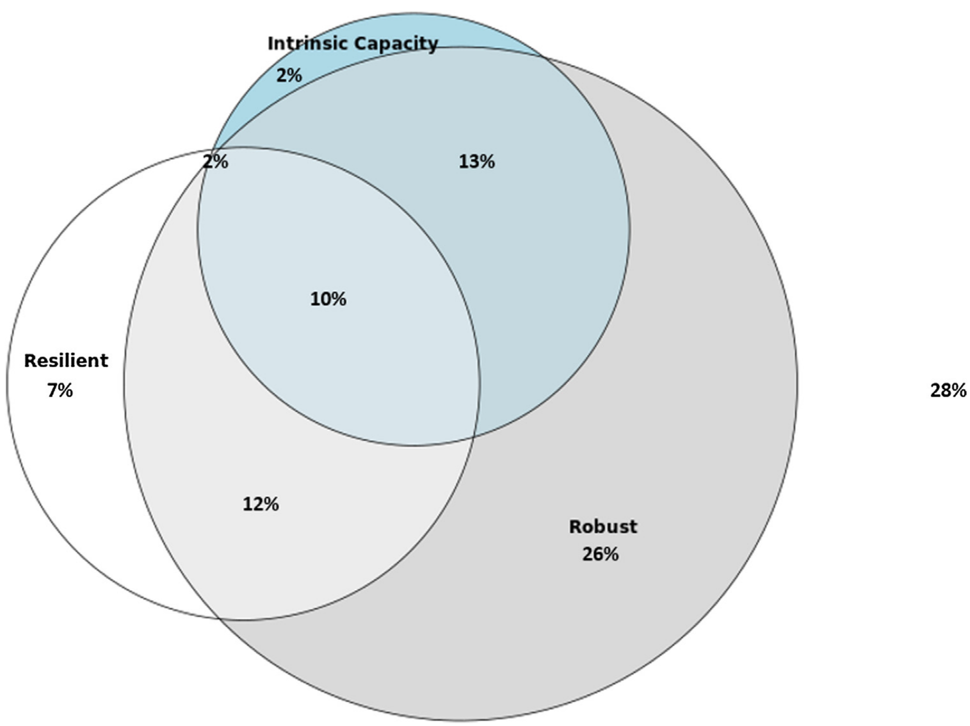

Fig. 1. Comparison of the prevalence and overlap of participants meeting the criteria for robustness, resilience and IC within the study population (n = 940), 272 participants (28%) had impairments according to all concepts.

4. Discussion

This is the first study to compare the three concepts robustness, resilience and IC regarding their associations with adverse health events. Robustness was inversely associated with the majority of the investigated health outcomes including falls, hospitalization, disability and all-cause mortality while IC and resilience were only associated with some of the examined outcomes. IC and resilience showed a considerable overlap with robustness, while around 26% of the study population were only robust.

4.1. Identification of the most useful concept for the prediction of adverse events

As robustness was independently and inversely associated falls, hospitalization and mortality in the 7-year follow-up and with disability in the 3-year follow-up, robustness emerged as the most useful concept in our study population. Previous studies support our findings especially concerning the relationship of robustness with falls and mortality [40,41]. Vermeiren et al. for example observed an increased risk for falls and mortality when applying the destructive approach of robustness, i.e., frailty or pre-frailty [40]. Contrary to our findings, frailty has also been associated with an increased risk for hospitalization especially for shorter follow-up times (≤12 months) [42,43], whereas in our study, robustness was only significantly inversely associated with hospitalization in the past 12 months based on the 7-year follow-up. A reason for the differing results might be the heterogenous definitions of frailty that have been applied [5,44].

In contrast to robustness, IC and resilience demonstrated independent inverse associations with disability for both follow-up times [45], but were not independently associated with falls, hospitalizations or mortality in the fully adjusted models. The difference compared to robustness might be explained by the construction of both concepts. In comparison to robustness, which consists of five mainly physical aspects [4], IC and resilience both include non-physical domains [10,24] which have previously been demonstrated as crucial aspects for the maintenance of abilities of daily living, especially during ageing [46,47]. Therefore, both physical and non-physical domains seem to be crucial for the maintenance of abilities, complementing the concept of a positive interplay between the mind and body [48] whereas for other outcomes such as falls or hospitalization especially physical domains seem to be decisive.

Even though all concepts showed protective associations with all-cause mortality, which has been confirmed by other authors [40,49,50], only robustness maintained the associations after adjusting for multimorbidity and medication use and therefore may be the most promising concept with regard to the prediction of all-cause mortality.

Taken together, all concepts presented different strengths regarding their associations with adverse health outcomes. As in daily clinical practice usually only one of the concepts is applied and in our study cohort robustness showed inverse associations with the majority of the investigated outcomes, robustness appears to be the most useful individual concept for the identification of future adverse health outcomes if resources are limited.

4.2. Frequency and overlap of robustness, resilience and intrinsic capacity

Even though, IC and robustness share many similar domains (e.g., locomotion, weight loss/vitality and exhaustion/depression) only 23% of the study population were both robust and had a high IC. In an Asian cohort by Chew et al. 37% of the study population were assigned to cluster 1 characterized by robustness and a high IC [51]. The observed difference compared to the present study might be due to the different analysis approaches and the inclusion of younger (mean 67.9 ± 7.9 years) participants [51]. The overall proportion of the study participants who met the criteria for high IC (26%) is in line with findings of other studies as for example, Liu et al. identified a stable or improved IC in approximately 24% of their study population [52]. In contrast, the proportion of 60% of participants meeting the criteria for robustness in the present study is rather high compared to previous studies. For example, Veronese et al. found that approximately 37% of different study populations met the criteria for robustness [53]. This difference might be explained by the higher prevalence of patients from hospitals or nursing homes in the study of Veronese et al. and by the use of a different method for the assessment of the robustness/frailty phenotype [53].

Even though IC and resilience showed similar associations with adverse health events, only 12% of all participants had a high IC and were resilient. Interestingly though, for robustness and resilience, as for robustness and IC, the overlap was 22% and 23%, respectively. Again, a physical-based concept such as robustness and concepts which also include non-physical domains such as resilience and IC seem to be present in some participants at the same time. Notably, it has been suggested that the concepts might beneficially influence each other [48,54]. In line with this, Stenroth et al. also assumed a strengthening effect of resilience on physiological reserves as depicted by a delay in the onset of frailty [14].

4.3. Future perspectives

In the regression analysis, robustness delivered the largest number of significant associations with the examined adverse health outcomes while resilience and IC were more strongly associated with disability. As some participants met the criteria for more than one of the concepts, further research on the interplay between the concepts is of interest. Belloni et al. for example suggested that IC might serve as a marker for the onset of frailty [12] and the addition of IC to frailty-evaluations has been shown to improve detection rates of high-risk patients [51].

4.4. Strengths and limitations

Robustness was identified as the most useful concept with regard to its significant associations with adverse health outcomes in this study cohort. Nevertheless, even for robustness or the opposing concept of frailty a standardized measurement tool is still lacking and different evaluation-concepts (frailty-phenotype, multidomain, accumulation of deficits) exist [5]. Also, one must notice that even within one frailty-assessment approach, domains might be evaluated by different measurement tools hampering their comparability [5]. Due to data availability in this study, a modified version of the Fried criteria had to be applied. Results from our study therefore could have been impacted by this modified frailty-phenotype approach. Additionally, also due to data availability the sensory domain of the IC-score had to be omitted and the locomotion domain was evaluated by the same test (TUG) for both, robustness and IC assessment. As we conducted these examinations in a population-based, relatively healthy study population, results might be different in other (acutely) sick patient cohorts. Additionally, as robustness and IC were identified by pre-defined threshold values, different thresholds would potentially have provided different results.

5. Conclusion

This is the first study to compare the three concepts robustness, IC and resilience with regard to their associations with adverse health events. Even though each concept has individual strengths, the primarily physically-based concept of robustness was identified as the most useful concept as it showed inverse associations with most of the examined adverse health outcomes including falls, disability, long-term hospitalization, and mortality. IC and resilience were mainly associated with a lower risk for the development of disabilities. As the latter two concepts include non-physical domains, this result supports a beneficial relationship between psychological capacities and physical skills later in life.

Author's contributions

M.R. performed the analysis and wrote the first draft of the manuscript. L.S., A.P., E.G., and B.T. collected the data. M.D., M.R., M.H. and B.T. conceptualized the research question and designed the methodology. M.D., M.H. and B.T. reviewed the analysis strategy. All authors revised and approved the final version of the manuscript.

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Data availability

The datasets presented in this article are not readily available because there is no participant consent for public data repositories. Requests to access the datasets should be directed to kora.passt@helmholtz-muenchen.de.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnha.2024.100433.

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