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The longitudinal relationship between intrinsic capacity, falls, and physical activity in Dutch older adults

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HIGHLIGHTS

- Higher baseline intrinsic capacity scores are associated with a lower fall risk over 3 years of follow-up and with higher physical activity levels over 3 and 6 years of follow-up in older adults.
- No evidence was found that physical activity mediates the relationship between intrinsic capacity and falls.
- The findings of this study contribute to the existing evidence that higher IC scores lead to better health outcomes in older adults.
- Further research is needed on the acceptability and effectiveness of IC measurement in clinical practice.

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ABSTRACT

Background: The relationship between intrinsic capacity (IC) and falls has not been studied in Western European older adults. This study aimed to examine the relationship between IC, falls, and physical activity (PA) in a Western European country, and to examine whether PA mediates the relation between IC and falls.
Methods: This study used data from community dwelling older adults from the Longitudinal Aging Study Amsterdam. Per participant, a baseline IC score was calculated (possible range 0–100). A Cox regression analysis ($n = 1257$) and a linear mixed model analysis ($n = 1874$) were used to examine the relation between IC and falls over a 3 year follow-up and between IC and PA over 3 and 6 years, respectively. A mediation analysis ($n = 898$) examined whether PA mediated the relation between IC and falls.
Results: Each one-point increase in IC score was associated with a 0.98 times lower 3-year fall hazard (95 % CI, 0.97–0.99). In older adults living in non-urban areas, those with the highest IC scores (range 71.7–92.5) spent on average 192 kcal/day more on PA (95 % CI, 127–256) than those with the lowest IC scores (range 26.5–63.0), while in older adults living in urban areas, those with the highest IC scores spent on average 89 kcal/day more on PA (95 % CI, 8–171). PA did not mediate the relationship between IC and falls.
Conclusion: Higher IC in older adults reduced fall risk and increased PA levels. Further research is needed on the acceptability and effectiveness of IC measurement in clinical practice.

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1. Introduction

Falls are a major global health concern among older adults. In the United States, one in four older adults fall every year (Kakara et al., 2023). Falls can have many consequences, including physical injuries, such as fractures and head wounds, loss of independence, reduced quality of life, chronic pain, fear of falling, reduced physical activity, loss in physical capabilities, social isolation, and increased healthcare utilization and institutionalization (Close et al., 2012; Jefferis et al., 2014; Lavedán et al., 2018; Petersen et al., 2020; Vaishya & Vaish, 2020; World Health Organization, 2021). As a result, falls are associated with considerable health care costs. It is estimated that in the United States, the total annual medical costs attributable to falls are approximately 50 billion dollars (Florence et al., 2018). As a consequence of population aging, the global number of falls and associated costs are expected to grow in the coming decades, emphasizing the need for effective fall prevention interventions (Montero-Odasso et al., 2022).

Falls have a complex etiology and are associated with many different risk factors, such as demographic characteristics (e.g. older age and female gender) (Li et al., 2022), medical history (e.g. depression or use of certain medications) (Jehu et al., 2021; Seppala et al., 2018), and cognitive impairments (e.g. dementia) (Fernando et al., 2017). In addition to the risk factors mentioned above, an innovative construct that may influence older adults' fall risk is their intrinsic capacity (IC). IC is defined as "the composition of all the physical and mental capacities that an individual can draw upon" (World Health Organization, 2015). IC was introduced by the World Health Organization (WHO) in 2015 as a construct that could enable the monitoring of health trajectories of older adults over time from a functional perspective rather than the traditional disease-oriented perspective (Chhetri, et al., 2021, 2022; Hamaker, et al., 2023). According to the WHO, IC is covered by five subdomains, namely the locomotion, cognition, sensory, psychological, and vitality domain. Together with relevant physical and social environmental characteristics, these domains determine an individual's functional ability, which is central to healthy aging (World Health Organization, 2015). Previous studies found that a higher composite IC score was associated with a lower probability of falls (Cacciatore et al., 2024; Chen et al., 2025; Cui et al., 2025; Muneera et al., 2023; Shi et al., 2023; Tay et al., 2023), multiple falls (Muneera et al., 2023; Shen et al., 2023; Shi et al., 2023), and fall-related injury (Muneera et al., 2023).

Although the abovementioned studies indicate that IC influences older adults' fall risk, most prospective studies have been conducted among Asian older adults (Cui et al., 2025; Muneera et al., 2023; Shen et al., 2023; Tay et al., 2023), and merely one in European older adults (Cacciatore et al., 2024). These results might not be generalizable to older adults worldwide, which emphasizes the need for additional prospective studies on the relationship between IC and falls in other parts of the world. In addition, none of the studies mentioned above measured falls according to the gold standard, which entails a prospective measurement using monthly fall calendars, postcards or diaries (Ganz et al., 2005; Griffin et al., 2019). Instead, participants were asked if they fell one or multiple times within a certain time frame (e.g., in the past three months or year). This method is known to lead to underreporting of falls, in particular non-injurious ones (Griffin et al., 2019). Therefore, the primary aim of this study is to assess the longitudinal relationship between IC and falls measured according to the gold standard in a Western-European country. Additionally, given that current research suggests that physical activity plays an important role in fall risk, secondary study aims are: (1) to examine the relation between IC and physical activity; and (2) to examine whether the relation between IC and falls is mediated by physical activity. The results of this study can be used to inform future fall prevention interventions for community-dwelling older adults.

2. Methods

2.1. Study design and participants

This study has a longitudinal design and used data from the Longitudinal Aging Study Amsterdam (LASA). LASA is a prospective cohort study among Dutch older adults that was set up to study the determinants and consequences of (changes in) physical, social, cognitive, and emotional functioning (Hoogendijk et al., 2020). The first measurement wave of LASA took place in 1992 and included a nationally representative sample of 3107 people between the ages of 55–84 years. This sample was based on a random selection from individuals listed in municipality registers. Thereby, men and the oldest old were oversampled to guarantee an adequate representation of very old men and the oldest old over time (Hoogendijk et al., 2020). Data have been collected every three years, resulting in over 30 years of follow-up data in 2025. Moreover, a second cohort of younger older adults (aged 55–64 years) was added in 2002–2003. Each measurement wave included a general interview, a medical interview including medical tests, and a self-administered survey. The LASA study has been approved by the Medical Ethical Committee of the VU University Medical Center and was executed in accordance with the guidelines of the Declaration of Helsinki (Hoogendijk et al., 2020).

This current study compared IC levels at baseline to the time to first fall during 3 years of follow-up, and to changes in PA over a 3- and 6-year follow-up period. A score for IC level was calculated for participants in the first cohort (aged 57–88 years) using data from the measurement wave in 1995–1996, and for participants in the second cohort (aged 57–68 years) using data from the measurement wave in 2005–2006. The IC score could only be calculated for subjects that participated in both the general and medical interview.

To analyze the relationship between IC and falls, data from participants in the first cohort aged 65 years and older were used. Thereby, falls were measured in the period from the medical interview in 1995–1996 until 1998–1999. Moreover, to analyze the relationship between IC and PA, data from participants in the first and second cohort with a valid IC score were merged. As a result, the measurement waves in 1995–1996 and 2005–2006 together formed the baseline analysis. Combining these cohorts widened the age range of the included subjects while also expanding the sample size (Koivunen et al., 2023). This analysis included a follow-up of PA levels after 3 and 6 years. Subjects were excluded if their PA level could not be calculated for any of these measurement waves.

2.2. Independent variable (intrinsic capacity)

An IC score was created using LASA data in a previous study (Koivunen et al., 2023). The researchers operationalized the IC score as a summary measure of individuals' capacities across the locomotion, cognition, sensory, psychological and vitality domain (Koivunen et al., 2023, 2022). Ultimately, 7 indicators of IC were selected, each covering at least one of the domains. Walking speed and balance were selected as indicators of locomotion, information processing speed as an indicator of cognition, self-reported vision (the ability to see clearly from a distance) and self-reported hearing (the ability to follow conversations in a group) as indicators of the sensory domain, self-efficacy as an indicator of the psychological domain, and hand grip strength as an indicator of the vitality domain. The operationalization of the selected indicators is explained in detail in the original article (Koivunen et al., 2023). The scales of all indicators were adapted to range from 0–100, whereby higher scores indicated better capacities. To calculate an IC score for each participant, a mean score was first calculated for domains with two indicators. Then, an overall IC score between 0–100 was calculated by taking the mean score of all the domains (Koivunen et al., 2023).

2.3. Outcome variables

2.3.1. Time to first fall

Older adults aged 65 years and older were asked to maintain a fall calendar for a 3-year period (from 1995–96 until 1998–99). During this period, participants were asked to record weekly whether or not they had fallen. Thereby, falls were defined as "an unintentional change in position resulting in coming to rest at a lower level or on the ground". Additionally, participants were instructed to mail their completed calendar sheets to the LASA office at the end of every three-month period. They were contacted by telephone if their calendar sheets were not received or if the returned calendar sheets were incomplete or filled in incorrectly (Longitudinal Aging Study Amsterdam, 2020a). Using the falls calendar data, it was determined whether the participant had a fall during the follow-up, including the time to first fall. Participants were excluded from this analysis if their fall status and/or time to first fall was missing.

2.3.2. Physical activity level

PA level was operationalized as the total number of kilocalories (kcal) that an individual estimated to have spent on PA per day (Longitudinal Aging Study Amsterdam, 2020b). Using the validated LASA Physical Activity Questionnaire (LAPAQ), participants were retrospectively asked how much time in the past two weeks they spent on the following activities: walking outside, biking, gardening, light household activities, heavy household activities, and the two other sports activities that they engaged in most often. In addition, participants were asked if their PA level in the past two weeks accurately represented their PA level during the rest of the year (Longitudinal Aging Study Amsterdam, 2020b). Participants were excluded from this current study if they answered this question with "no". To calculate the total number of kcal spent on PA per day, Metabolic Equivalent of Task (MET) scores were used, which were assigned to all activities in the LAPAQ, and the duration of each activity was taken into account (Longitudinal Aging Study Amsterdam, 2020b). To prevent the calculation of PA levels from being influenced by atypical values, a participant was excluded from a measurement wave if they reported spending $\geq$ 300 min per day on a particular activity in that measurement wave, unless the participant also reported a similar time spent on that activity in a previous or subsequent wave (with a maximum deviation of $\pm$ 60 min).

2.4. Covariates

2.4.1. Potential moderator

The urbanization level of people's living area (i.e., the mean number of addresses per square kilometer within a radius of one kilometer) was included as a potential moderating variable. This was done because previous studies indicated that aspects of the physical neighborhood environment can affect the relation between IC and health outcomes (Lu et al., 2021). Hence, the relation between IC and falls and/or PA may be different for people living in urban compared to non-urban areas. In LASA, data on the urbanization level of participants' living area were obtained from Statistics Netherlands. A cut-off point of 1500 addresses/km^2 was used to distinguish urban from non-urban living areas (Statistics, Netherlands).

2.4.2. Potential confounders

Potential confounding variables were identified based on previous studies on the relationship between IC and health outcomes (Cacciatore et al., 2024; Muneera et al., 2023; Tay et al., 2023), and included age, sex, educational level, partner status, number of chronic diseases, polypharmacy, depressive symptoms, alcohol use and smoking status. Since two cohorts (cohort 1 and 2) were combined to study the relation between IC and PA, cohort was also included as a confounder in this analysis. Data on age (in years) and sex (male and female) were obtained from population registries. Partner status was categorized as "partner" and "no partner". Education level was categorized as "low" (elementary education or less), "middle" (lower vocational education and general intermediate education), and "high" (intermediate vocational education, general secondary education, higher vocational education, college education, and university). The number of chronic diseases (categorized as none, 1 chronic disease and $\geq$2 chronic diseases) was self-reported and based on a list of the 7 most prevalent chronic diseases among Dutch older adults: 1) chronic non-specific lung disease, 2) cardiac disease, 3) peripheral arterial disease, 4) diabetes mellitus, 5) cerebrovascular accident, 6) arthritis, and 7) cancer (Longitudinal Aging Study Amsterdam, 2023). Polypharmacy was defined as the simultaneous use of at least five medications at the same time (Halli-Tierney et al., 2019). In LASA, medication use was determined by the interviewer based on the patients' medication containers that were prescribed by a physician and used in the past two weeks (Longitudinal Aging Study Amsterdam, 2019b) . Depressive symptoms were measured using the Center for Epidemiological Studies Depression Scale (CES-D); a self-reported questionnaire that comprises 20 items about depressive symptoms that were experienced in the previous week. The total CES-D score can range from 0–60, whereby higher scores reflect more depressive symptoms. A score of 16 or higher was used to identify people with clinically relevant depressive symptoms (Longitudinal Aging Study Amsterdam, 2019a). Alcohol use (yes and no) and smoking status (yes and no) were both self-reported.

2.4.3. Potential mediator

PA level was considered a potential mediator in the relationship between IC and falls.

2.5. Statistical analysis

Baseline characteristics of the study samples are presented separately for participants included in the analysis of the relationship between IC and falls (reported separately for participants who fell and did not fall), and IC and PA (reported separately for participants living in urban and non-urban areas). Categorical variables were reported with a number and percentage. Continuous variables with a normal distribution were reported with a mean and standard deviation (SD), while a median and interquartile range (IQR) were reported for continuous variables with a skewed distribution.

To analyze the relationship between IC and time to first fall, a Cox regression analysis was performed. Before conducting the analysis, linearity between the continuous independent variables and the endpoint variable (fall status) was checked, and the proportional hazards assumption was tested. In the analysis, IC was included as a categorical variable based on tertiles, allowing for a group-based (low, intermediate and high IC scores) comparison of fall hazard. In case IC was linearly related to fall status, it was also included as a continuous variable. Three statistical models were made. In the first model, age and sex were included as covariates. After reporting this association, "urbanization level" and the interaction between this variable and the IC tertiles were added to the model. Further analyses were stratified for urbanization level if the *p*-value of at least one of the interaction terms was $<$0.10. If not, urbanization level was included as a confounder. In the second model, education level and partner status were added, and in the third model, the number of chronic diseases, polypharmacy, depressive symptoms, alcohol use, and smoking status were added.

To examine the relationship between IC and PA, a linear mixed model analysis was performed with PA level (at baseline, and at the 3-year and 6-year follow-up) as the outcome variable. Prior to the data analysis, several assumptions were tested, namely: linearity of the relationship between the continuous independent variables and the dependent variable; the absence of multicollinearity; homoscedasticity of the residuals, and a normal distribution of the residuals (Schielzeth et al., 2020). Again, IC score was included as a categorical variable based on tertiles, but also as a continuous variable if there was linearity between IC score and PA level. Moreover, the same statistical models were made as those in analysis of IC and falls. However, since this was a longitudinal analysis including 2 cohorts, this model was also corrected for "cohort", and included a random intercept on the level of the individual to correct for the dependency of the repeated observations of subjects (Twisk, 2013). Since linear mixed models are robust against missing data, participants were included in this analysis if they had a value for PA for at least one of the three measurement waves (Twisk et al., 2013).

Finally, a mediation analysis was performed to identify a potentially mediating effect of PA in the relation between IC and falls. In this analysis, fall status (yes/no) over a 3-year follow-up was used as the outcome variable, IC level at baseline as the independent variable, and PA level at baseline as the potential mediator. Hereby, it was assumed that a high/low IC precedes a high/low PA level. The mediation analysis was corrected for all potential confounders.

All data were operationalized in SPSS Statistics (version 28) and analyzed in Stata (version 17), except for the mediation analysis which was also performed in SPSS using the PROCESS macro (v 4.2) by Andrew F. Hayes (Hayes, 2022). Significance was set at $p < 0.05$.

3. Results

3.1. characteristics of participants

Fig. 1 shows the inclusion process of participants in this study. The baseline sample of cohort 1 was drawn from the measurement wave in 1995–1996 ($n = 2545$). Of these participants, 1257 were included in the analysis on IC and falls. Additionally, 1175 participants from cohort 1 were included in the analysis on IC and PA. In addition, the baseline sample of cohort 2 was extracted from the measurement wave in 2005–2006 ($n = 908$). In total 699 participants from cohort 2 were included in the analysis on IC and PA. Hence, by combining cohort 1 and 2, 1874 participants were included in the analysis of IC and PA.

The baseline characteristics of the participants in the analysis of IC and falls are presented in Table 1. The characteristics are presented separately for participants that had a fall during the 3-year follow-up ($n = 685$, 54.5 %) and participants that did not fall ($n = 572$). Complete follow-up data were received from 1151 participants. In total, 466 (81.5 %) out of the 572 participants for which no fall was reported completed the entire follow-up period. The remaining participants ($n = 106$, 18.5 %) were lost to follow-up and censored at the time of their last follow-up. The median follow-up duration of these participants was 69.4 weeks [IQR 39.0 – 116.6]. In participants that fell, the median time to first fall was 43.0 weeks [IQR 17.0 – 85.0]. The median age of participants who fell (75.0, IQR 69.9 – 81.2) was significantly higher than the median age of participants who did not fall (74.0, IQR 69.2 – 79.8). Also, the proportion of females was significantly higher among participants who fell (55.5 %) compared to those who did not fall (44.8 %). Participants who fell also had a significantly lower median IC score (63.0, IQR 55.0 – 69.4) than those who did not fall (64.9, IQR 57.9 – 71.0). Additionally, compared to participants that did not fall, those that fell significantly less frequently had a partner (57.1 % vs. 63.3 %),

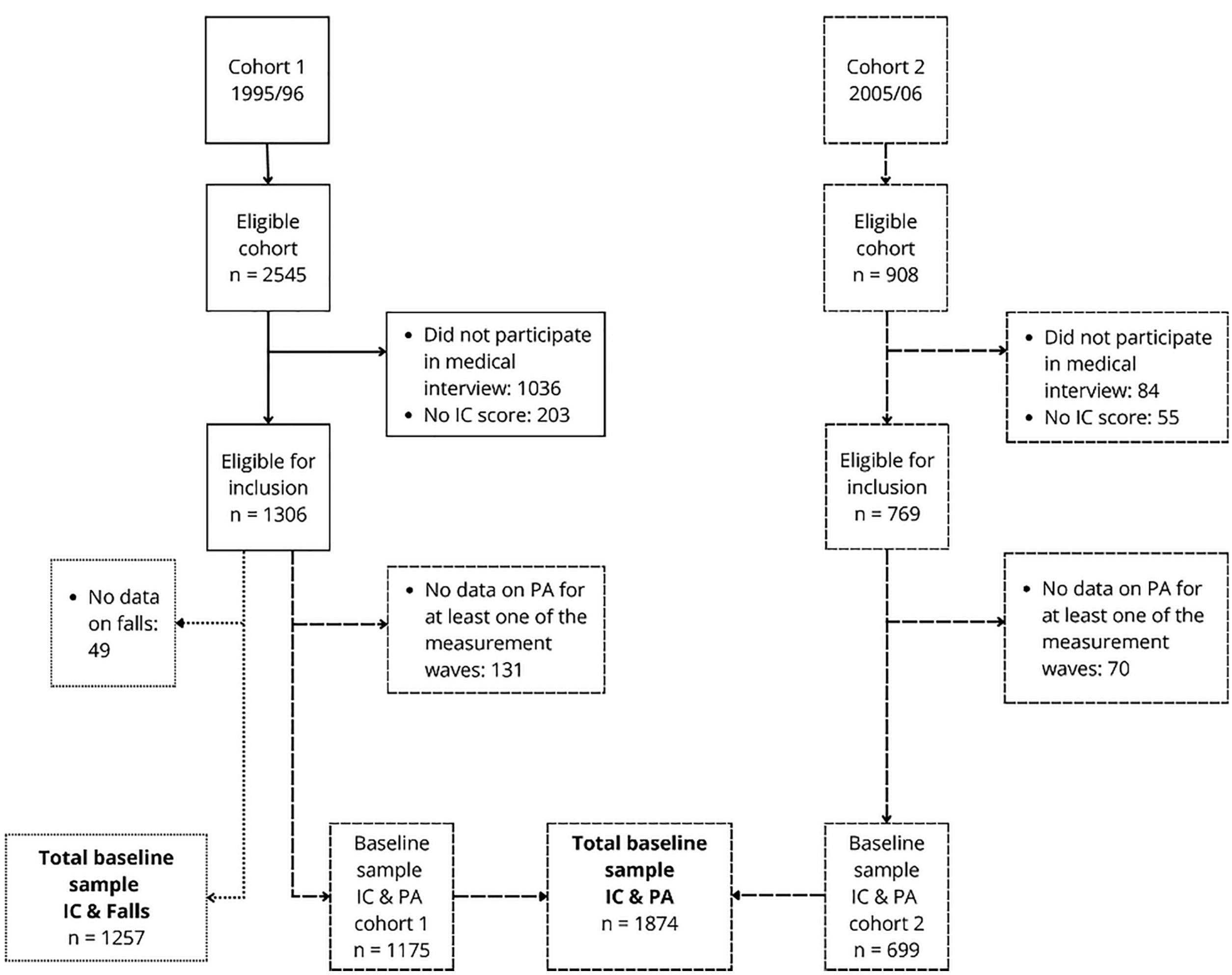

Fig. 1. Flowchart of the inclusion process of study participants from cohort 1 and 2 in the analysis of the relationship between IC and falls (dotted line), and IC and PA (dashed line).

Table 1
Baseline characteristics of the participants included in the analysis of the relation between intrinsic capacity and falls in older adults.

	Fall during follow-up = yes (*n* = 685)	Fall during follow-up = no (*n* = 572)	*p* value
Age (years)[a]	75.0 [69.9 – 81.2]	74.0 [69.2 – 79.8]	0.04*
Sex (female)[b]	380 (55.5)	256 (44.8)	<0.001*
Time to first fall (weeks)[a]	43.0 [17.0 – 85.0]	N/A	N/A
Intrinsic capacity score (0–100)[a]	63.0 [55.0 – 69.4]	64.9 [57.9 – 71.0]	<0.001*
Education level[b]			
Low	261 (38.2)	238 (41.6)	0.34
Middle	216 (31.6)	180 (31.5)	
High	207 (30.3)	154 (26.9)	
Partner (yes)[b]	391 (57.1)	364 (63.6)	0.02*
Nr. of chronic diseases[b]			
0	166 (24.2)	181 (31.6)	<0.01*
1	254 (37.1)	210 (36.7)	
≥ 2	265 (38.7)	181 (31.6)	
Polypharmacy (yes)[b,c]	110 (16.1)	71 (12.4)	0.07
Depressive symptoms (yes)	99 (14.5)	66 (11.6)	0.13
Urbanization level[b]			
Low	397 (58.0)	351 (61.4)	0.21
High	288 (42.0)	220 (38.5)	
Alcohol use (yes)[b]	529 (77.2)	437 (76.4)	0.73
Smoking (yes)[b]	115 (16.8)	124 (21.7)	0.03*
Physical activity level (kcal/day spent on physical activity)[d]	511 [295 – 784]	554 [330 – 872]	0.13

Note. 685 participants had a fall during the follow-up, and 572 participants did not fall.
[a] Presented as median [interquartile range] – Mann Whitney U test.
[b] Presented as *n* (percentage) – chi2 test.
[c] Polypharmacy was defined as the simultaneous use of five or more medicines.
[d] Physical activity level had 483 missings in the group of participants who fell, and 419 missings among participants who did not fall.

significantly more often had one or multiple chronic diseases (37.1 % and 38.7 % vs. 36.7 % and 31.6 %), and smoked significantly less frequently (16.8 % vs. 21.7 %).

Table 2 presents the baseline characteristics of the participants in the analysis of IC and PA. In total, 1874 participants were included. Of these participants, 637 (34.0 %) had a known value for PA level for one measurement wave, 716 participants (38.2 %) for two measurement waves and 521 participants (27.8 %) for all three measurement waves (data not shown). In addition to the characteristics of the total study sample (n = 1874), the characteristics are presented separately for people living in a non-urban area (n = 1130) and urban area (n = 744), because the statistical analysis indicated that the type of living area moderated the relationship between IC and PA. The median IC score of the total sample was 67.7 (IQR, 59.9 – 73.6), and was not significantly different for urban participants compared to non-urban participants. However, compared to urban participants, non-urban participants significantly more often had a partner (71.8 % vs. 63.8 %), significantly less frequently suffered from depressive symptoms (10.3 % vs. 14.7 %), significantly less often consumed alcohol (81.1 % vs. 84.7 %), and significantly less often used 5 or more medicines simultaneously (11.2 % vs. 15.5 %). Finally, the percentage of participants with two or more chronic diseases was significantly higher in urban participants (34.8 %) than in non-urban participants (26.5 %).

Table 3 shows the PA level of both the total and stratified sample at each measurement wave. In the total sample, the median number of kcal/day spent on PA was 567 (IQR 334 - 880) at baseline (n = 1477), which was 554 kcal/day (IQR, 336 - 867) at the 3-year follow-up (n = 1199), and 529 kcal/day (IQR, 329 - 819) at the 6-year follow-up (n = 956). At each measurement point, the PA level of non-urban participants

Table 2
Baseline characteristics of the participants included in the analysis of the relationship between intrinsic capacity & physical activity, including a stratification for the type of living area ("not urban" versus "urban").

	Total sample (*n* = 1874)	Living area = not urban (*n* = 1130)	Living area = urban (*n* = 744)	*p* value
Age (years)[a]	68.7 [64.7 – 76.9]	68.3 [64.7 – 76.25]	69.6 [64.7 – 77.9]	0.11
Sex (female)[b]	960 (51.2)	574 (50.8)	386 (51.9)	0.65
Intrinsic capacity score[a]	67.7 [59.9 – 73.6]	68.0 [60.4 – 73.7]	67.5 [59.0 – 73.5]	0.18
Partner (yes)[b]	1286 (68.6)	811 (71.8)	475 (63.8)	<0.001*
Education level[b]				
Low	609 (32.5)	382 (33.8)	227 (30.6)	
Middle	636 (34.0)	389 (34.4)	247 (33.2)	0.12
High	628 (33.5)	359 (31.8)	269 (36.2)	
Nr. of chronic diseases[b]				
None	590 (31.5)	387 (34.2)	203 (27.3)	
1	726 (38.7)	444 (39.3)	282 (37.9)	<0.001*
2	558 (29.8)	299 (26.5)	259 (34.8)	
Polypharmacy (yes)[b]	241 (12.9)	126 (11.2)	115 (15.5)	0.01*
Depressive symptoms (yes)[b]	225 (12.0)	116 (10.3)	109 (14.7)	0.004*
Alcohol use (yes)[b]	1546 (82.5)	916 (81.1)	630 (84.7)	0.04*
Current smoker (yes)[b]	389 (20.8)	219 (19.4)	170 (22.8)	0.07

Note. The total sample included 1874 participants, of which 1130 lived in a non-urban area, and 744 in an urban area.
[a] Presented as median [interquartile range] - Mann Whitney U test.
[b] Presented as *n* (percentage) - chi2 test.

Table 3
Median physical activity level[a] per measurement wave of the total study sample and the sample stratified for the type of living area ("not urban" versus "urban").

	Total sample	Living area: not urban	Living area: urban	*p* value
Baseline[b]	567 [334 – 880] (*n* = 1477)	601 [354 – 923] (*n* = 869)	533 [313 – 791] (*n* = 608)	0.001*
3-year follow-up[b]	554 [336 – 867] (*n* = 1199)	576 [354 – 883] (*n* = 741)	521 [310 – 822] (*n* = 458)	0.01*
6-year follow-up[b]	529 [329 – 819] (*n* = 956)	548 [338 – 853] (*n* = 592)	495 [312 – 739] (*n* = 364)	0.02*

Note. The total sample included 1874 participants, of which 1130 lived in a non-urban area, and 744 in an urban area.
[a] Physical activity level was operationalized as the total kcal/day spent on physical activity.
[b] Reported as median [interquartile range] – Mann Whitney U test.
[*] $p < 0.05$.

was significantly higher as compared to urban participants.

3.2. Association between intrinsic capacity and time to first fall

The results of the complete statistical analysis are presented in Table 1 (see Supplementary file). All statistical assumptions were met. Since no interaction was found between IC and type of living area (p = 0.67, p = 0.41, and p = 0.66 for "IC tertile 2*Urban", "IC tertile 3*Urban" and "IC score*Urban", respectively), the results are presented unstratified. Model 1 shows that after correcting for sex and age, participants with the highest IC scores (tertile 3) had a 0.68 times lower hazard on a fall during 3-years of follow-up (95 % CI, 0.55 - 0.84) compared to participants with the lowest IC scores. However, participants in IC tertile 2 did not have a significantly lower hazard on a fall compared to participants with the lowest IC scores (HR = 0.85, 95 % CI 0.71–1.03). After correcting for additional socio-demographic and health-related variables, similar effect estimates were obtained, with only participants in IC tertile 3 showing a significantly lower hazard on a fall compared to participants in IC tertile 1 (see Model 2 and Model 3). Fig. 2 shows the survival curve of falls for participants in each IC tertile based on the fully adjusted statistical model.

3.3. Longitudinal association between intrinsic capacity and physical activity

Table 4 shows the results of the linear mixed model analysis of the relationship between IC and PA. Since the linearity assumption was not met, IC score and age were included as categorical variables based on tertiles. In addition, the homoscedasticity assumption was not met. Therefore, robust standard errors were used in the analyses to account for heteroscedasticity. The remaining assumptions were met.

Since an interaction was found between the IC tertiles and type of living area ($p = 0.001$ and $p = 0.006$ for "IC tertile 2*Urban" and "IC tertile 3*Urban", respectively), the analyses were performed separately for participants living in urban and non-urban areas. Model 2 shows that after correcting for several socio-demographic variables, non-urban participants in IC tertile 2 on average spent 179 kcal/day (95 % CI, 126 – 233) more on PA than non-urban participants in IC tertile 1. In addition, non-urban participants in IC tertile 3 spent on average 213 kcal/day (95 % CI, 150 – 275) more on PA than those in IC tertile 1. Among urban participants, only those with the highest IC scores spent significantly more kcal/day on PA than participants in the first tertile (β = 98, 95 % CI 17 – 178). An additional correction for health-related variables (see Model 3) yielded similar results for both urban and non-urban participants.

3.4. Mediation analysis

The result of the mediation analysis is presented in Table 2 (see Supplementary file). In total, 898 participants from cohort 1 were included in this analysis, because the remaining participants ($n = 359$) from the analysis of IC and falls had no data on baseline PA level. There was a significant effect of baseline IC on baseline PA levels. Compared to

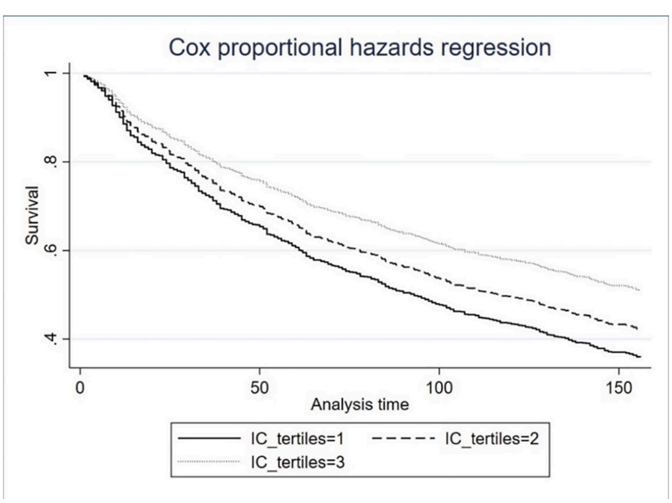

Fig. 2. Survival curve of the relationship between IC and falls, presented separately for participants in each IC tertile. Analysis time is presented in weeks. IC tertile 1 comprises participants with the lowest IC scores. This figure is based on the fully adjusted statistical model (corrected for age, sex, education level, partner status, number of chronic diseases, polypharmacy, depressive symptoms, alcohol use and smoking status).

Table 4
Linear mixed model analysis of the relationship between intrinsic capacity (IC) and physical activity[a] in older adults.

	Model 1	Model 2		Model 3	
	Total sample β (95% CI)	Living area: Not urban β (95% CI)	Living area: Urban β (95% CI)	Living area: Not urban β (95% CI)	Living area: Urban β (95% CI)
IC tertile (score)[b]					
1 (26.5 – 63.0)	Ref.	Ref.	Ref.	Ref.	Ref.
2 (63.0 – 71.7)	128 (87 – 170)**	179 (126 – 233)**	51 (-14 – 116)	172 (118 - 226)**	42 (-24 – 108)
3 (71.7 – 92.5)	157 (109– 206)**	213 (150 – 275)**	98 (17 – 178)*	192 (127 – 256)**	89 (8 – 171)*

Note. β = regression coefficient, 95 % CI = 95 % Confidence Interval, Ref. = reference group. The analysis included 1874 respondents.
[a] Physical activity was operationalized as the total kcal/day spent on physical activity.
[b] IC was operationalized as a categorical variable based on tertiles. The reference group (tertile 1) comprises participants with lowest IC scores
Model 1: corrected for age, sex and cohort
Model 2: corrected for age, sex, cohort, education level, and partner status
Model 3: corrected for age, sex, cohort, education level, partner status, nr. of chronic diseases, polypharmacy, depressive symptoms, alcohol use and smoking status.
* $p < 0.05$
** $p < 0.01$.

participants with the lowest IC scores (tertile 1), those in the second tertile spent on average 102 kcal/day more on PA (95 % CI, 31 – 173), and those in the third tertile on average 175 more kcal/day (95 % CI, 94 – 257). However, there was no significant effect of baseline PA level on fall status. With every one-point increase in kcal/day spent on PA, the log-odds of a fall were 0.0001 lower (95 % CI, −0.0004 – 0.0002; linearity was checked). In addition, there was a significant relationship between IC and fall status. Participants with the highest IC scores (tertile 3) had a 0.42 lower log odds of a fall (95 % CI, −0.83 - −0.02) than participants with the lowest IC scores (tertile 1). The indirect effect of IC through PA was not statistically significant, indicating that the effect of IC on fall status was not mediated by PA.

4. Discussion

This study found that older adults with higher baseline composite IC scores had a lower hazard on a fall over 3 years of follow-up compared to older adults with lower baseline IC scores. Additionally, this study found that higher baseline IC scores were associated with higher PA levels over a 3- and 6-year follow-up. Thereby, the effect of IC on PA was larger in older adults living in non-urban areas compared to older adults living in urban areas. No evidence was found for a mediating effect of PA in the relationship between IC and falls in older adults.

In summary, across several studies, higher IC scores were consistently associated with a lower risk of falling among older adults, despite differences in IC score ranges and follow-up periods. In the current study (possible IC range 0–100), each one-point increase in IC score was associated with a 0.98 times lower fall hazard. In comparison, studies in Asian populations using a 0–10 IC scale found similar protective associations with odds ranging between 0.64–0.8 (Muneera et al., 2023; Shen et al., 2023; Tay et al., 2023). In addition to Asian older adults, Cacciatore et al. (2024) found that a one-point higher IC score (range 0–100) was associated with a 0.96 times lower fall risk in the past three months in Italian older adults. Furthermore, Chen et al. (2025) studied trajectories of IC in American older adults. Compared to participants with persistently low IC scores, those with persistently moderate and persistently high scores had a 0.87 and 0.74 times lower fall risk over a 4-year follow-up, respectively. This is similar to our study, in which participants in the second IC tertile and those in the highest tertile had a 0.84 and 0.66 times lower fall risk over 3 years of follow-up compared to participants in the lowest tertile, respectively. The protective effect of higher IC on falls may be explained by the fact that the IC construct is composed of indicators that are known to influence the fall risk of older adults. For example, previous studies already demonstrated that low hand grip strength (vitality domain) (Pham et al., 2023), balance impairments (locomotion domain) (Muir et al., 2010), and cognitive impairments (cognition domain) (Muir et al., 2012) increase fall risk in older adults.

To our knowledge, the effect of IC on PA levels has not been studied before. However, previous studies did reveal that higher IC has a significant protective effect on functional decline (Beard et al., 2022; Stolz et al., 2022; Waris et al., 2022) and frailty (Tay et al., 2023). Since PA levels tend to be lower in older adults who experience these negative health outcomes (Paterson & Warburton, 2010; Rogers et al., 2017; Zhao et al., 2022), the finding that higher IC scores also positively influence PA levels is congruent with these previous results.

The effect of urbanization level on the relation between IC and PA has also not been studied before. The smaller effect of IC on PA in people living in urban areas could imply that higher IC scores are less needed to maintain higher PA levels in this group. Possibly, because older adults living in urban areas have various facilities in their near proximity that allow them to be active despite a lower IC. This theory is in accordance with the Healthy Aging Framework by the WHO, in which it is stated that functional ability is determined by the interplay between IC and relevant environmental characteristics (World Health Organization, 2015). In contrast, this study did not find that urbanization influenced the relation between IC and time to first fall. Possibly, no relevant differences in neighborhood characteristics that may influence fall risk exist between urban and non-urban areas in The Netherlands (e.g. equal distribution of pedestrian friendly infrastructure). However, since no previous studies have assessed this, more research is needed to assess if also in other settings/countries urbanization does not moderate the relation between IC and falls as well as specific components such as walkability.

Finally, this study did not find a mediating effect of PA on the association between IC and falls. Although baseline IC had a significant effect on baseline PA and on fall status over a 3-year follow-up, no significant effect of PA on fall status was found. The latter finding is notable, since recent systematic reviews and meta-analyses do suggest that PA and exercise protect older adults against falls (Sherrington et al., 2020; Thibaud et al., 2012). Perhaps the lack of statistical significance in this current study could be explained by the fact that this study used a relatively broad measure of PA, which included not merely sports activities, but, for example, also gardening and light household activities. We therefore performed a post hoc sensitivity analysis creating a PA variable that was restricted to intense activities, including only sports activities (e.g., long distance cycling or walking, running, swimming and ball sports). The results of the post hoc sensitivity analysis are presented in Table 3 (see Supplementary file 3). In this analysis, too, no association was found between IC and sports activities, and sports activities did not mediate the relationship between IC and falls. Although further studies should be conducted, the insignificant indirect could imply that PA does not (always) play a relevant role in the relation between IC and falls. Presumably, the role of PA also depends on the IC domains affected. Therefore, future research should explore the influence of the separate domains on fall risk, and in which domains, if any, PA plays a mediating role.

This study has several strengths and limitations. Strengths include the use of a validated, multi-component IC score, the large study sample that was obtained from a nationally representative sample of Dutch older adults, and the prospective measurement of both falls and PA. Additionally, to our knowledge, this was the first study on IC and falls in which falls were measured according to the gold standard, namely prospectively using fall calendars. This method allows participants to record falls in real time, reducing the risk of recall bias (Griffin et al., 2019). In previous studies, falls were examined by either a health care professional, through a direct question or questionnaire or a telephonic interview. These methods have been shown to lead to the underreporting of falls, primarily because older adults may forget fall incidents, especially non-injurious ones (Griffin et al., 2019).

A limitation of this study is that the IC score was only determined at baseline measurement and that possible changes in IC levels during follow-up were not assessed. Particularly older adults are at risk of deteriorating IC levels during aging (World Health Organization, 2015). If this decline occurs, it may further increase the risk of falls and low PA levels. As this study did not account for changes in IC over time, the protective effect of higher levels of IC on falls and low PA levels may be underestimated. To gain more insight in the impact of changes in IC levels on falls, low PA levels, and other health outcomes, it is recommended that future studies employ longitudinal assessments of IC. In addition, a limitation is that not all participants had a known PA level at each measurement point. In our study, participants were included if they had a PA value for at least one of the measurement waves. While the linear mixed model analysis allows for the inclusion of participants with some missing outcome data, it is likely that missing data occurred more frequently in older adults with low IC. This could have led to an underestimation of the protective effect of higher IC on PA. Therefore, future studies incorporating prospective measurements of IC are needed to validate the findings of this study and to further explore the relationship between IC and PA. Another limitation is that, although there is agreement on the definition of IC and its domains, no globally standardized method exists for assessing IC domains and for quantifying and scoring composite IC scores. As a result, the methods used to establish IC scores differ across studies (López-Ortiz et al., 2022), including previous studies on IC and falls. This lack of standardization hampers cross-study comparability and the implementation of IC assessment in clinical practice. Finally, a limitation is that the IC score was categorized based on tertiles, rather than on clinically meaningful cut-off points, because currently no such cut-off points exist. Therefore, future studies should establish clinically relevant cut-off points for distinguishing people with lower IC scores from those with intermediate and higher scores.

The results of the current study indicate that higher IC levels in older adults can contribute to a lower fall risk and higher PA levels. In this study, we chose to investigate composite IC scores rather than separate domains, because previous research already established that (indicators of) separate IC domains are associated with falls and PA. Moreover, gaining greater insight into the total IC score and its relationship with health outcomes is highly relevant, as the WHO recommends to monitor IC as a measure of overall health status. For example, (Beard & Chen, 2023) propose that the IC of older adults should be measured repeatedly in clinical practice, allowing the IC score and its progression over time to be compared with population norms (which are already available for some countries). Consequently, low IC scores (compared to population norms) and impairments over time may prompt clinicians to conduct a more detailed IC evaluation, including assessment of the individual domains, which can then guide the development of individualized interventions. A low composite IC score or a decline over time may also serve as a warning sign that the individual is at increased risk of falling and may be less physically active, which might prompt the clinician to ask the patient about falls and PA or perform an additional fall analysis. However, additional research should be conducted before the measurement of IC can effectively be implemented in clinical practice. For instance, as stated in the article by Hoogendijk et al. (2023) evidence on the feasibility and acceptance of IC measurement in clinical practice is lacking. Moreover, it is unclear whether the implementation of IC will result in better care for older adults, and whether it is cost-effective compared to care as usual. Finally, the acceptability to older adults to be evaluated in terms of their IC remains to be explored (Hoogendijk et al., 2023).

5. Conclusion

This study showed that higher IC levels in Dutch older adults decreased their fall risk and contributed to higher PA levels, the latter especially in older adults living in non-urban areas. These findings contribute to the existing evidence that higher IC scores lead to better health outcomes in older adults, and underline the potential benefits of the implementation of IC measurement in clinical practice. However, before the measurement of IC can successfully be implemented in clinical care, more research should be conducted on the acceptability of this implementation (in both clinicians and patients) and its effectiveness (in terms of both health outcomes and costs).

CRediT authorship contribution statement

Wesna Belimbegovski: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Laura A. Schaap:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Annemiek J. Linn:** Writing – review & editing, Supervision, Conceptualization. **Stephanie Medlock:** Writing – review & editing, Visualization, Supervision, Methodology, Conceptualization. **Julia C.M. van Weert:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Nathalie van der Velde:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Natasja M. van Schoor:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.archger.2025.105936.

References

Beard, J. R., & Chen, M. (2023). Intrinsic capacity as a composite outcome measure: Opportunities and challenges. *The Journal of Nutrition, Health and Aging, 27*(6), 398–400. https://doi.org/10.1007/s12603-023-1923-z

Beard, J. R., Si, Y., Liu, Z., Chenoweth, L., & Hanewald, K. (2022). Intrinsic capacity: Validation of a new WHO concept for healthy aging in a longitudinal Chinese study. *The Journals of Gerontology: Series A, 77*(1), 94–100. https://doi.org/10.1093/gerona/glab226

Cacciatore, S., Marzetti, E., Calvani, R., Picca, A., Salini, S., Russo, A., Tosato, M., & Landi, F. (2024). Intrinsic capacity and recent falls in adults 80 years and older living in the community: Results from the ilSIRENTE study. *Aging Clinical and Experimental Research, 36*(1), 169. https://doi.org/10.1007/s40520-024-02822-7

Chen, X., He, L., Shi, K., Wen, Q., Yu, Q., Gao, M., & Fang, Y. (2025). Intrinsic capacity trajectories: Implications for subsequent falls and hospitalizations among older adults. *The Journals of Gerontology: Series A, 80*(5). https://doi.org/10.1093/gerona/glaf017

Chhetri, J. K., Harwood, R. H., Ma, L., Michel, J.-P., & Chan, P. (2022). Intrinsic capacity and healthy ageing. *Age and Ageing, 51*(11), 1–3. https://doi.org/10.1093/ageing/afac239

Chhetri, J. K., Xue, Q. L., Ma, L., Chan, P., & Varadhan, R. (2021). Intrinsic capacity as a determinant of physical resilience in older adults. *The Journal of Nutrition Health and Aging, 25*(8), 1006–1011. https://doi.org/10.1007/s12603-021-1629-z

Close, J. C. T., Lord, S. R., Antonova, E., Martin, M., Lensberg, B., Taylor, M., Hallen, J., & Kelly, A. (2012). Older people presenting to the emergency department after a fall: A population with substantial recurrent healthcare use. *Emergency Medicine Journal, 29*(9), 742. https://doi.org/10.1136/emermed-2011-200380

Cui, Y., Zhou, J., Liu, Q., Ye, H., & Liu, B. (2025). The mediating role of intrinsic capacity in balance and falls among older adults. *Scientific Reports, 15*(1), Article 11732. https://doi.org/10.1038/s41598-025-96081-9

Fernando, E., Fraser, M., Hendriksen, J., Kim, C. H., & Muir-Hunter, S. W. (2017). Risk factors associated with falls in older adults with dementia: A systematic review. *Physiotherapy Canada, 69*(2), 161–170. https://doi.org/10.3138/ptc.2016-14

Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical costs of fatal and nonfatal falls in older adults. *Journal of the American Geriatrics Society, 66*(4), 693–698. https://doi.org/10.1111/jgs.15304

Ganz, D. A., Higashi, T., & Rubenstein, L. Z. (2005). Monitoring falls in cohort studies of community-dwelling older people: Effect of the recall interval. *The Journal of the American Geriatrics Society, 53*(12), 2190–2194. https://doi.org/10.1111/j.1532-5415.2005.00509.x

Griffin, J., Lall, R., Bruce, J., Withers, E., Finnegan, S., Lamb, S. E., Lamb, S. E., Underwood, M., Martin, F., Yardley, L., Skelton, D., Willett, K., Eldridge, S., Slowther, A.-M., Duggan, S., Bruce, J., Hennings, S., Withers, E., Mant, R., … Adjei, H. (2019). Comparison of alternative falls data collection methods in the prevention of falls injury trial (PreFIT). *Journal of Clinical Epidemiology, 106*, 32–40. https://doi.org/10.1016/j.jclinepi.2018.09.006

Halli-Tierney, A. D., Scarbrough, C., & Carroll, D. (2019). Polypharmacy: Evaluating risks and deprescribing. *American Family Physician, 100*(1), 32–38.

Hamaker, M., Gijzel, S., Rostoft, S., & van den Bos, F. (2023). Intrinsic capacity and resilience: Taking frailty to the next level. *Journal of Geriatric Oncology, 14*(2), Article 101421. https://doi.org/10.1016/j.jgo.2022.101421

Hayes, A. F. (2022). *Introduction to mediation, moderation, and conditional process analysis: A regression based approach*. Guilford Press.

Hoogendijk, E. O., Deeg, D. J. H., de Breij, S., Klokgieters, S. S., Kok, A. A. L., Stringa, N., Timmermans, E. J., van Schoor, N. M., van Zutphen, E. M., van der Horst, M., Poppelaars, J., Malhoe, P., & Huisman, M. (2020). The longitudinal aging study Amsterdam: Cohort update 2019 and additional data collections. *European Journal of Epidemiology, 35*(1), 61–74. https://doi.org/10.1007/s10654-019-00541-2

Hoogendijk, E. O., Dent, E., & Koivunen, K. (2023). Intrinsic capacity: An under-researched concept in geriatrics. *Age and Ageing, 52*(10). https://doi.org/10.1093/ageing/afad183

Jefferis, B. J., Iliffe, S., Kendrick, D., Kerse, N., Trost, S., Lennon, L. T., Ash, S., Sartini, C., Morris, R. W., Wannamethee, S. G., & Whincup, P. H. (2014). How are falls and fear of falling associated with objectively measured physical activity in a cohort of community-dwelling older men? *BMC Geriatrics, 14*(1), 114. https://doi.org/10.1186/1471-2318-14-114

Jehu, D. A., Davis, J. C., Falck, R. S., Bennett, K. J., Tai, D., Souza, M. F., Cavalcante, B. R., Zhao, M., & Liu-Ambrose, T. (2021). Risk factors for recurrent falls in older adults: A systematic review with meta-analysis. *Maturitas, 144*, 23–28. https://doi.org/10.1016/j.maturitas.2020.10.021

Kakara, R., Bergen, G., Burns, E., & Stevens, M. (2023). Nonfatal and fatal falls among adults aged ≥65 years - United States, 2020-2021. *Morbidity and Mortality Weekly Report, 72*(35), 938–943. https://doi.org/10.15585/mmwr.mm7235a1

Koivunen, K., Hoogendijk, E. O., Schaap, L. A., Huisman, M., Heymans, M. W., & van Schoor, N. M. (2023). Development and validation of an intrinsic capacity composite score in the longitudinal aging study Amsterdam: A formative approach. *Aging Clinical and Experimental Research, 35*(4), 815–825. https://doi.org/10.1007/s40520-023-02366-2

Koivunen, K., Schaap, L. A., Hoogendijk, E. O., Schoonmade, L. J., Huisman, M., & van Schoor, N. M. (2022). Exploring the conceptual framework and measurement model of intrinsic capacity defined by the World Health Organization: A scoping review. *Ageing Research Reviews, 80*, Article 101685. https://doi.org/10.1016/j.arr.2022.101685

Lavedán, A., Viladrosa, M., Jürschik, P., Botigué, T., Nuín, C., Masot, O., & Lavedán, R. (2018). Fear of falling in community-dwelling older adults: A cause of falls, a consequence, or both? *PLoS One, 13*(3), Article e0194967. https://doi.org/10.1371/journal.pone.0194967

Li, Y., Hou, L., Zhao, H., Xie, R., Yi, Y., & Ding, X. (2022). Risk factors for falls among community-dwelling older adults: A systematic review and meta-analysis. *Frontiers in Medicine, 9*, Article 1019094. https://doi.org/10.3389/fmed.2022.1019094

Longitudinal Aging Study Amsterdam. (2019a). *Depressive Symptoms*. https://lasa-vu.nl/topics/depressive-symptoms/.

Longitudinal Aging Study Amsterdam. (2023). *Self-report of chronic diseases*. https://lasa-vu.nl/topics/self-report-chronic-diseases/.

Longitudinal Aging Study Amsterdam. (2019b). March 19, 2019 *Medication and Food Supplement Use* https://lasa-vu.nl/topics/medication-use/.

Longitudinal Aging Study Amsterdam. (2020a). April 14, 2020 *Falls*. Retrieved August 29, 2024 from https://lasa-vu.nl/topics/falls/.

Longitudinal Aging Study Amsterdam. (2020b). April 24, 2020 *Physical Activity*. Retrieved February 28, 2023 from https://lasa-vu.nl/topics/physical-activity/#:~:Text=Physical %20activity %20is %20an %20important, %2C %20fractures %2C %20depressive %20symptoms %20etc.

López-Ortiz, S., Lista, S., Peñín-Grandes, S., Pinto-Fraga, J., Valenzuela, P. L., Nisticò, R., Emanuele, E., Lucia, A., & Santos-Lozano, A. (2022). Defining and assessing intrinsic capacity in older people: A systematic review and a proposed scoring system. *Ageing Research Reviews, 79*, Article 101640. https://doi.org/10.1016/j.arr.2022.101640

Lu, S., Liu, Y., Guo, Y., Ho, H. C., Song, Y., Cheng, W., Chui, C. H. K., Chan, O. F., Webster, C., Chiu, R. L. H., & Lum, T. Y. S. (2021). Neighbourhood physical environment, intrinsic capacity, and 4-year late-life functional ability trajectories of low-income Chinese older population: A longitudinal study with the parallel process of latent growth curve modelling. *EClinicalMedicine, 36*, Article 100927. https://doi.org/10.1016/j.eclinm.2021.100927

Montero-Odasso, M., van der Velde, N., Martin, F. C., Petrovic, M., Tan, M. P., Ryg, J., … Masud, T. (2022). World guidelines for falls prevention and management for older adults: A global initiative. *Age and Ageing, 51*(9), 1–36. https://doi.org/10.1093/ageing/afac205

Muir, S. W., Berg, K., Chesworth, B., Klar, N., & Speechley, M. (2010). Quantifying the magnitude of risk for balance impairment on falls in community-dwelling older adults: A systematic review and meta-analysis. *Journal of Clinical Epidemiology, 63*(4), 389–406. https://doi.org/10.1016/j.jclinepi.2009.06.010

Muir, S. W., Gopaul, K., & Montero Odasso, M. M. (2012). The role of cognitive impairment in fall risk among older adults: A systematic review and meta-analysis. *Age and Ageing, 41*(3), 299–308. https://doi.org/10.1093/ageing/afs012

Muneera, K., Muhammad, T., Pai, M., Ahmed, W., & Althaf, S. (2023). Associations between intrinsic capacity, functional difficulty, and fall outcomes among older adults in India. *Scientific Reports, 13*(1), 9829. https://doi.org/10.1038/s41598-023-37097-x

Paterson, D. H., & Warburton, D. E. (2010). Physical activity and functional limitations in older adults: A systematic review related to Canada's physical activity guidelines. *International Journal of Behavioral Nutrition and Physical Activity, 7*, 38. https://doi.org/10.1186/1479-5868-7-38

Petersen, N., König, H.-H., & Hajek, A. (2020). The link between falls, social isolation and loneliness: A systematic review. *Archives of Gerontology and Geriatrics, 88*, Article 104020. https://doi.org/10.1016/j.archger.2020.104020

Pham, T., McNeil, J. J., Barker, A. L., Orchard, S. G., Newman, A. B., Robb, C., Ernst, M. E., Espinoza, S., Woods, R. L., Nelson, M. R., Beilin, L., & Hussain, S. M. (2023). Longitudinal association between handgrip strength, gait speed and risk of serious falls in a community-dwelling older population. *PLoS One, 18*(5), Article e0285530. https://doi.org/10.1371/journal.pone.0285530

Rogers, N. T., Marshall, A., Roberts, C. H., Demakakos, P., Steptoe, A., & Scholes, S. (2017). Physical activity and trajectories of frailty among older adults: Evidence from the english longitudinal study of ageing. *PLoS One, 12*(2), Article e0170878. https://doi.org/10.1371/journal.pone.0170878

Schielzeth, H., Dingemanse, N. J., Nakagawa, S., Westneat, D. F., Allegue, H., Teplitsky, C., … Araya-Ajoy, Y. G. (2020). Robustness of linear mixed-effects models to violations of distributional assumptions. *Methods in Ecology and Evolution, 11*(9), 1141–1152. https://doi.org/10.1111/2041-210X.13434

Seppala, L. J., van de Glind, E. M. M., Daams, J. G., Ploegmakers, K. J., de Vries, M., Wermelink, A. M. A. T., van der Velde, N., Blain, H., Bousquet, J., Bucht, G., Caballero-Mora, M. A., van der Cammen, T., Eklund, P., Emmelot-Vonk, M., Gustafson, Y., Hartikainen, S., Kenny, R. A., Laflamme, L., Landi, F., & & van der Velde, N. (2018). Fall-risk-increasing drugs: A systematic review and meta-analysis: III. Others. *Journal of the American Medical Directors Association, 19*(4), 372. https://doi.org/10.1016/j.jamda.2017.12.099. e371-372.e378.

Shen, S., Xie, Y., Zeng, X., Chen, L., Guan, H., Yang, Y., Wu, X., & Chen, X. (2023). Associations of intrinsic capacity, fall risk and frailty in old inpatients. *Frontiers in Public Health, 11*, Article 1177812. https://doi.org/10.3389/fpubh.2023.1177812

Sherrington, C., Fairhall, N., Kwok, W., Wallbank, G., Tiedemann, A., Michaleff, Z. A., Ng, C. A. C. M., & Bauman, A. (2020). Evidence on physical activity and falls prevention for people aged 65+ years: Systematic review to inform the WHO guidelines on physical activity and sedentary behaviour. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 144. https://doi.org/10.1186/s12966-020-01041-3

Shi, K., He, L., Chen, X., & Fang, Y. (2023). Prospective association of intrinsic capacity with falls and multiple falls in older adults (NHATS). *Innovation in Aging, 7*(Suppl 1), 1102. https://doi.org/10.1093/geroni/igad104.3539

Statistics Netherlands. *Urban Area*. Retrieved March 15, 2023 from https://www.cbs.nl/en-gb/our-services/methods/definitions/urban-area.

Stolz, E., Mayerl, H., Freidl, W., Roller-Wirnsberger, R., & Gill, T. M. (2022). Intrinsic capacity predicts negative health outcomes in older adults. *The Journals of Gerontology: Series A, 77*(1), 101–105. https://doi.org/10.1093/gerona/glab279

Tay, L., Tay, E. L., Mah, S. M., Latib, A., Koh, C., & Ng, Y. S. (2023). Association of intrinsic capacity with frailty, physical fitness and adverse health outcomes in community-dwelling older adults. *The Journal of Frailty & Aging, 12*(1), 7–15. https://doi.org/10.14283/jfa.2022.28

Thibaud, M., Bloch, F., Tournoux-Facon, C., Brèque, C., Rigaud, A. S., Dugué, B., & Kemoun, G. (2012). Impact of physical activity and sedentary behaviour on fall risks in older people: A systematic review and meta-analysis of observational studies. *European Review of Aging and Physical Activity, 9*(1), 5–15. https://doi.org/10.1007/s11556-011-0081-1

Twisk, J., de Boer, M., de Vente, W., & Heymans, M. (2013). Multiple imputation of missing values was not necessary before performing a longitudinal mixed-model analysis. *Journal of Clinical Epidemiology, 66*(9), 1022–1028. https://doi.org/10.1016/j.jclinepi.2013.03.017

Twisk, J. W. R. (2013). *Applied longitudinal data analysis for epidemiology: A practical guide* (2 ed). Cambridge University Press.

Vaishya, R., & Vaish, A. (2020). Falls in older adults are serious. *Indian Journal of Orthopaedics, 54*(1), 69–74. https://doi.org/10.1007/s43465-019-00037-x

Waris, M., Upadhyay, A. D., Chatterjee, P., Chakrawarty, A., Kumar, P., & Dey, A. B. (2022). Establishment of clinical construct of intrinsic capacity in older adults and its prediction of functional decline. *Clinical Interventions in Aging, 17*, 1569–1580. https://doi.org/10.2147/cia.S371793

World Health Organization. (2015). *World Report on Ageing and Health*. https://iris.who.int/bitstream/handle/10665/186463/9789240694811_eng.pdf?sequence=1.

World Health Organization. (2021). April 26, 2021 *Falls* https://www.who.int/news-room/fact-sheets/detail/falls.

Zhao, W., Hu, P., Sun, W., Wu, W., Zhang, J., Deng, H., Huang, J., Ukawa, S., Lu, J., Tamakoshi, A., & Liu, X. (2022). Effect of physical activity on the risk of frailty: A systematic review and meta-analysis. *PLoS One, 17*(12), Article e0278226. https://doi.org/10.1371/journal.pone.0278226