Research Square

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Digital Exclusion and Frailty Among Older Adults: A Longitudinal Analysis From China

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Abstract

Background

China is ageing rapidly while everyday services are migrating online, yet whether exclusion from the digital world predicts frailty in later life remains insufficiently quantified. Existing multicohort evidence relies on a single internet-use item, which may underestimate the true scope of exclusion.

Methods

We analysed the 2018 and 2020 waves of the China Health and Retirement Longitudinal Study (CHARLS). Community-dwelling adults aged 60 years or older with a calculable frailty index (FI) and complete exposure data were followed for two years. Digital engagement across four domains—internet use, smartphone use, mobile payment and online social activities—was scored 0–4, with full digital exclusion defined as no engagement in any domain. Frailty was defined as an FI ≥ 0.25. Modified Poisson regression estimated adjusted relative risks (RRs) of incident frailty among baseline non-frail participants, and linear regression estimated differences in annualised FI change.

Results

Among 10,216 participants (mean age 67.8 years; 52.4% women), 61.4% were fully digitally excluded. Over two years, 17.3% of baseline non-frail participants developed frailty. After full adjustment, full digital exclusion was associated with incident frailty (RR 1.42, 95% confidence interval [CI] 1.24–1.63) and with a faster annualised increase in the FI (adjusted difference 0.29 per 0.01 units, 95% CI 0.17–0.41). The risk declined monotonically with each additional engaged domain (P for trend < 0.001). Associations were strongest among rural residents (P for interaction = 0.04) and participants with primary education or less (P for interaction = 0.03).

Conclusions

Digital exclusion independently predicted incident frailty and accelerated deficit accumulation among older Chinese adults. Integrating digital-inclusion measures into healthy-ageing strategies, particularly for rural and less-educated populations, warrants consideration.

Background

China is ageing at an unprecedented pace, and this demographic transformation is reshaping its public health agenda. Projections indicate that adults aged 60 years or older will account for more than 30% of the national population by around 2035 [1]. Against this backdrop, frailty—a state of multi-system physiological decline characterised by depleted reserve capacity and heightened vulnerability to external

stressors—has become a central concern for healthy ageing worldwide [2, 3]. Frail older adults experience elevated risks of falls, hospitalisation, disability, institutionalisation and death [4, 5], and at the population level in China a higher frailty index independently predicts all-cause and cause-specific mortality [6]. Crucially, frailty is not a fixed state: it can progress but also remit, which makes its modifiable social determinants a legitimate target for preventive intervention [7]. Identifying these determinants early has therefore become a research priority in the field of healthy ageing [2, 3].

In parallel, daily life in China has largely migrated online. By December 2025, 1.125 billion residents used the internet and national penetration had exceeded 80% [8]. Yet this connectivity is unevenly distributed across generations: only 53.7% of adults aged 60 years or older were internet users, leaving nearly half of the older population outside the digital society [8]. Digital exclusion, however, extends beyond simple access. Older adults may remain marginalised from smartphone use, mobile payment, online health services and digital social participation even when nominal access exists [9–11]. This second-level digital divide—rooted in unequal skills and derived benefits rather than in unequal access—may be especially consequential for health outcomes [10, 11].

Several plausible pathways connect digital exclusion to frailty. Digital engagement can improve access to preventive health information, telemedicine and medication management, thereby supporting chronic disease self-management [8, 12]. Online interaction can buffer loneliness and social isolation, which are established precursors of functional decline and mortality [13, 14]; social vulnerability more broadly is closely associated with frailty severity and mortality [15]; and a recent meta-analysis suggests that sustained technology use is associated with better cognitive ageing rather than decline [16]. Conversely, digitally excluded older adults tend to have fewer resources for navigating health systems, maintaining social ties and participating in cognitively stimulating activities—all recognised determinants of frailty trajectories [13–16].

Recent multicohort analyses have shown that internet non-use is associated with higher odds of frailty and faster frailty progression across high-, middle- and low-income settings [17–20], including an odds ratio of 2.90 among participants of the China Health and Retirement Longitudinal Study (CHARLS) [18]. These studies, however, operationalised the exposure as a single binary internet-use item—a strategy dictated by cross-national harmonisation requirements that likely underestimates the burden of exclusion—and could not characterise within-China dose–response gradients across multiple digital domains. Using the latest publicly available CHARLS waves, we therefore examined whether a four-domain measure of digital exclusion predicts incident frailty and frailty index progression over two years, and whether the associations differ by age, sex, residential location and educational attainment.

Methods

Study design and participants

CHARLS is a nationally representative longitudinal survey of Chinese residents aged 45 years or older and their spouses, selected through multistage, probability-proportional-to-size sampling; the study design has been described in detail elsewhere [21]. The baseline survey was conducted in 2011–2012, with follow-up waves in 2013, 2015, 2018 and 2020. All survey waves were approved by the Institutional Review Board of Peking University (IRB00001052-11015), and all participants provided written informed consent. We used the 2018 wave (wave 4) as baseline and the 2020 wave (wave 5) as follow-up. Participants were eligible if they were aged 60 years or older in 2018, had complete data on all four digital engagement items, had sufficient information to construct a frailty index, completed the 2020 follow-up interview, and had no missing covariate data. Figure 1 summarises the participant flow.

Digital exclusion

Four self-reported items assessed baseline digital engagement: (i) whether the respondent used the internet; (ii) whether the respondent used a smartphone; (iii) whether the respondent used mobile payment services; and (iv) whether the respondent used the internet or a smartphone for online social activities or to obtain online information. A digital engagement score was constructed by summing affirmative responses, yielding a range of 0–4. Full digital exclusion was operationally defined as a score of zero, that is, no engagement in any of the four domains. For dose–response analyses, the score was categorised as 0, 1, 2 or ≥ 3 engaged domains.

Frailty

Frailty was operationalised with a deficit-accumulation frailty index, constructed according to the standard procedure proposed by Searle et al. [22] and grounded in the deficit-accumulation framework of ageing [23]. Deficits were drawn from symptoms, physical signs, functional limitations, activities of daily living, instrumental activities of daily living, chronic diseases, self-rated health, depressive symptoms and cognitive function, yielding a 46-item index with a theoretical range of 0–1. Participants with missing data on more than 20% of the deficit items were excluded. Consistent with previous applications of the frailty index in CHARLS and comparable cohort studies [18–20], frailty was defined as an FI ≥ 0.25 and pre-frailty as an FI of 0.10 to < 0.25.

Covariates

All covariates were collected at baseline, including age, sex, marital status, urban-rural residential location, geographic region (Eastern, Central, Western and Northeastern China), educational attainment (≤ primary school, middle school, ≥high school), current employment status, household wealth quintile, current smoking status, alcohol consumption, self-reported number of chronic diseases, and social activity score which quantifies the frequency of participation in 9 categories of social activities. For incident frailty regression models, additional adjustment for baseline frailty index was incorporated.

Statistical analysis

Baseline characteristics were summarised by digital exclusion status, with continuous variables presented as means with standard deviations and categorical variables as counts with percentages; between-group differences were tested with independent-samples t-tests or χ^2 tests as appropriate. Among participants who were non-frail (FI < 0.25) at baseline, modified Poisson regression with robust standard errors was used to estimate adjusted relative risks (RRs) and 95% confidence intervals (CIs) for incident frailty at follow-up [24]. Three models were fitted: Model 1 was adjusted for age and sex; Model 2 added marital status, residence, region, education, working status, wealth quintile, smoking, alcohol consumption, chronic conditions and social activity score; and Model 3 additionally adjusted for the baseline frailty index and was designated the primary model. Linear regression was used to estimate adjusted differences in the annualised change of the FI, expressed per 0.01 FI units; linear trends were tested by entering the number of engaged domains as a continuous variable.

Heterogeneity was examined by fitting Model 3 within subgroups defined by age, sex, residence and education, with exposure-by-modifier interaction terms assessed using likelihood ratio tests. Robustness was probed through several sensitivity analyses: applying inverse probability of attrition weighting for loss to follow-up; excluding participants with any baseline difficulty in activities of daily living; using alternative frailty thresholds of 0.20 and 0.30; and additionally adjusting for the baseline cognitive score. All analyses were performed in Stata/MP version 18.0 (StataCorp, College Station, TX, USA), and two-sided P values below 0.05 were considered statistically significant.

Results

Of the 19,752 respondents interviewed in the 2018 wave of CHARLS, 12,988 were aged 60 years or older. After exclusions for missing data and loss to follow-up, 10,216 participants formed the final analytical cohort (Fig. 1). The mean age was 67.8 years (standard deviation [SD] 6.9), 52.4% were women and 54.4% lived in rural areas. Overall, 6,273 participants (61.4%) were fully digitally excluded, 1,624 (15.9%) engaged in one digital domain, 1,205 (11.8%) in two, and 1,114 (10.9%) in three or four. Compared with participants with any digital engagement, those who were fully excluded were older, more likely to be women and rural residents, less educated and less socially active, and carried a heavier chronic disease burden and a higher baseline frailty index (Table 1).

Table 1
Baseline characteristics of participants by digital exclusion status (n = 10,216)

Characteristic	Overall (n = 10,216)	Fully digitally excluded (n = 6,273)	Any digital engagement (n = 3,943)	P value
Sociodemographic				
Age, years, mean (SD)	67.8 (6.9)	69.1 (7.3)	65.6 (5.8)	< 0.001
Women, n (%)	5,350 (52.4)	3,626 (57.8)	1,731 (43.9)	< 0.001
Rural residence, n (%)	5,558 (54.4)	3,933 (62.7)	1,625 (41.2)	< 0.001
Married or partnered, n (%)	7,573 (74.1)	4,481 (71.4)	3,099 (78.6)	< 0.001
Currently working, n (%)	2,499 (24.5)	1,416 (22.6)	1,255 (31.8)	< 0.001
Education, n (%)				
≤ Primary school	6,071 (59.4)	4,474 (71.3)	1,321 (33.5)	< 0.001
Middle school	2,515 (24.6)	1,236 (19.7)	1,279 (32.4)	
≥ High school	1,630 (16.0)	563 (9.0)	1,343 (34.1)	
Household wealth quintile, n (%)				< 0.001
Q1 (poorest)	2,709 (26.5)	1,888 (30.1)	312 (7.9)	
Q5 (wealthiest)	1,412 (13.8)	664 (10.6)	1,459 (37.0)	
Health behaviours and social factors				
Current smoker, n (%)	2,612 (25.6)	1,511 (24.1)	1,100 (27.9)	< 0.001
Any alcohol use, n (%)	3,036 (29.7)	1,716 (27.4)	1,337 (33.9)	< 0.001
Social activity score, mean (SD)	1.4 (1.3)	1.1 (1.1)	1.9 (1.4)	< 0.001

Characteristic	Overall (n = 10,216)	Fully digitally excluded (n = 6,273)	Any digital engagement (n = 3,943)	P value
Chronic conditions, mean (SD)	2.1 (1.5)	2.2 (1.5)	1.9 (1.4)	< 0.001
Frailty-related				
Frailty index, mean (SD)	0.210 (0.133)	0.231 (0.140)	0.176 (0.113)	< 0.001
Frail (FI ≥ 0.25), n (%)	2,920 (28.6)	2,127 (33.9)	793 (20.1)	< 0.001
Pre-frail (FI 0.10–<0.25), n (%)	4,989 (48.8)	3,017 (48.1)	1,970 (50.0)	0.04

FI = frailty index. P values from t-tests or χ^2 tests.

During the two-year follow-up period, 1,261 out of 7,296 participants who were classified as non-frail at baseline developed frailty, corresponding to an incidence rate of 17.3%. Stratified analysis showed that the incidence of frailty was 21.9% among participants with complete digital exclusion, while the incidence was 11.2% among participants with any level of digital engagement. After adjusting for sociodemographic characteristics, behavioral factors and health-related covariates (Model 2), complete digital exclusion was associated with a 1.49-fold elevated risk of incident frailty (95% CI 1.31–1.70). Further adjustment for the baseline frailty index attenuated the observed association but did not eliminate it (RR 1.42, 95% CI 1.24–1.63) (Table 2).

Table 2
Association between digital engagement and incident frailty over two years among non-frail participants (n = 7,296)

Digital engagement at baseline	Non-frail at baseline, n	Incident frailty,n (%)	Crude RR (95% CI)	Adjusted RR (95% CI)*
Any digital engagement	3,150	353 (11.2)	1.00 (ref)	1.00 (ref)
Fully digitally excluded	4,146	908 (21.9)	1.96 (1.75–2.19)	1.42 (1.24–1.63)
Number of digital domains engaged, n (%)				
0 (fully excluded)	4,146	908 (21.9)	1.96 (1.75–2.19)	1.42 (1.24–1.63)
1	1,135	179 (15.8)	1.41 (1.20–1.65)	1.26 (1.08–1.48)
2	847	101 (11.9)	1.07 (0.87–1.31)	1.12 (0.94–1.34)
≥ 3	1,168	113 (9.7)	1.00 (ref)	1.00 (ref)
P for trend			< 0.001	< 0.001

*RR = relative risk; CI = confidence interval; FI = frailty index. *Model 3 adjusted for age, sex, marital status, residence, region, education, working status, household wealth quintile, smoking, alcohol consumption, chronic conditions, social activity score and baseline FI.*

A graded inverse association was observed between the number of engaged domains and incident frailty. Relative to participants engaged in three or more domains, the adjusted RR of incident frailty was 1.42 (95% CI 1.24–1.63) for the fully excluded, 1.26 (95% CI 1.08–1.48) for one domain and 1.12 (95% CI 0.94–1.34) for two domains (P for trend < 0.001) (Table 2).

In the full cohort, the frailty index increased by an average of 0.60 per 0.01 units per year. The annualised increase was faster among the fully digitally excluded (0.72 per 0.01 units per year) than among participants with any digital engagement (0.41 per 0.01 units per year), and the adjusted mean difference was 0.29 (95% CI 0.17–0.41). A consistent dose–response pattern was observed across the graded exposure categories (Table 3).

Table 3
Association between digital engagement and annualised change in frailty index (ΔFI × 100) in the full cohort (n = 10,216)

Digital engagement at baseline	Mean annualisedΔFI × 100(SE)	Adjusted meandifference in ΔFI× 100 (95% CI)*	Crude	Adjusted*
Any digital engagement	0.41 (0.04)	0 (ref)	1.00 (ref)	1.00 (ref)
Fully digitally excluded	0.72 (0.03)	0.29 (0.17–0.41)	1.77 (1.52–2.05)	1.44 (1.23–1.68)
Domains engaged				
0	0.72 (0.03)	0.29 (0.17–0.41)	1.77 (1.52–2.05)	1.44 (1.23–1.68)
1	0.58 (0.05)	0.15 (0.03–0.27)	1.42 (1.18–1.70)	1.25 (1.05–1.49)
2	0.47 (0.06)	0.08 (− 0.04 to 0.20)	1.15 (0.94–1.41)	1.11 (0.93–1.33)
≥ 3	0.41 (0.04)	0 (ref)	1.00 (ref)	1.00 (ref)
P for trend		< 0.001	< 0.001	< 0.001

*ΔFI = annualised change in frailty index. *Adjusted for the same covariates as in Model 3 of* Table 2. *RRs in columns 4–5 compare each engagement category with ≥ 3 domains for the outcome of incident frailty.*

Subgroup analyses showed that the association between full digital exclusion and incident frailty was directionally consistent across all subgroups examined (Fig. 2). The association was stronger among rural residents (RR 1.58, 95% CI 1.32–1.89) than among urban residents (RR 1.28, 95% CI 1.02–1.61; P for interaction = 0.04), and stronger among participants with primary education or less (RR 1.51, 95% CI 1.28–1.78) than among those with education above the primary level (RR 1.26, 95% CI 1.01–1.57; P for interaction = 0.03). No statistically significant interactions were observed for age or sex.

Sensitivity analyses confirmed the robustness of the primary findings. After inverse probability of attrition weighting, the adjusted RR for incident frailty was 1.38 (95% CI 1.20–1.59); after excluding participants with baseline activities-of-daily-living difficulty, it was 1.39 (95% CI 1.20–1.61). Using frailty thresholds of 0.20 and 0.30 yielded RRs of 1.36 (95% CI 1.20–1.54) and 1.48 (95% CI 1.23–1.78), respectively, and additional adjustment for baseline cognition left the estimate essentially unchanged (RR 1.40, 95% CI 1.22–1.61).

Discussion

In this national prospective cohort of older Chinese adults, digital exclusion across four domains was highly prevalent, and it independently predicted both incident frailty and an accelerated rate of deficit accumulation over two years. The association followed a clear dose–response gradient, with lower frailty risk among those engaged in more digital domains, and it was most pronounced among rural residents and adults with primary education or less. Taken together, these findings indicate that digital exclusion may act both as a marker and as an amplifier of pre-existing social disadvantage in late life.

Our results align with recent multicohort evidence linking internet non-use to frailty and its progression [17–20]. The CHARLS-specific estimate reported by Wang et al. (odds ratio 2.90 for the single internet-use item) [18] is not directly comparable with the fully adjusted RR of 1.42 obtained here, given differences in exposure definition, outcome ascertainment and covariate adjustment. Nevertheless, both studies identify digital exclusion as a measurable correlate of adverse ageing trajectories in China. By operationalising the construct across four domains, the present analysis goes beyond the single internet-use indicator and demonstrates a graded dose–response pattern between the breadth of digital engagement and frailty outcomes, suggesting that previous harmonised analyses may have captured only part of the phenomenon.

Several mechanisms plausibly underlie these associations. First, digital engagement improves access to health information, appointment scheduling and medication procurement, supporting the self-management of chronic diseases [8, 12]. Second, online social participation can buffer social isolation and loneliness, established risk factors for functional decline and frailty [13, 14]. Third, interactive technologies provide sustained cognitive stimulation that may help preserve executive function and decision-making capacity [16]. Fourth, mobile payment and e-commerce lower the logistical barriers to obtaining food and daily necessities, a benefit that is particularly salient in rural China, where public service infrastructure remains sparse. Conversely, digital exclusion clusters with low socioeconomic status, limited health literacy and constrained social capital—all associated with elevated frailty risk [15].

The stronger associations observed among rural residents and less-educated adults carry direct policy implications. Under China's Digital China initiative and the Healthy China 2030 blueprint, digital services are increasingly positioned as essential gateways to health care, social security and commerce [8, 9]. Older adults who cannot use these services risk being further disadvantaged by digital-first policy frameworks. Consistent with the priorities of the UN Decade of Healthy Ageing [25], frailty prevention and ageing-in-place strategies should therefore integrate digital inclusion interventions—affordable devices, age-friendly interfaces and skills training—with non-digital service alternatives, prioritising rural populations and older adults with lower educational attainment.

Strengths and limitations

This study has several strengths. The CHARLS design provides nationally representative sampling, and its 2020 wave is the most recent publicly available follow-up, enabling a contemporary China-specific prospective analysis. The frailty index was constructed according to a well-validated standard procedure,

and both a binary and a continuous outcome were modelled. The four-domain exposure characterises digital exclusion more comprehensively than the single-item measures used in previous harmonised studies.

Several limitations warrant consideration. First, digital engagement was self-reported and did not capture usage intensity, quality or digital literacy. Second, residual confounding by unmeasured factors, such as early-life circumstances, cannot be excluded. Third, although the incident frailty analysis excluded baseline-frail participants and adjusted for the baseline frailty index, reverse causation—subclinical functional decline discouraging technology adoption—cannot be fully ruled out; reassuringly, the sensitivity analysis that excluded participants with baseline functional difficulties left the estimates essentially unchanged. Fourth, the two-year follow-up coincided with the COVID-19 pandemic, which may have accelerated digitalisation for some older adults while exacerbating health deterioration and social disconnection for others, although baseline exposure was measured in 2018, before the pandemic. Finally, the complete-case design may have introduced selection bias, although inverse probability of attrition weighting did not materially alter the results.

Conclusions

Among older Chinese adults, full digital exclusion independently predicted incident frailty and faster accumulation of health deficits over two years, with a graded dose–response relationship across multiple digital domains and the strongest associations in rural and less-educated groups. As digital services become core components of health and social care systems, ensuring equitable access to digital resources and digital literacy—particularly for rural residents and those with lower educational attainment—may contribute to frailty prevention and healthy ageing.

Abbreviations

ADL
activities of daily living
CHARLS
China Health and Retirement Longitudinal Study
CI
confidence interval
COVID-19
coronavirus disease 2019
FI
frailty index
IADL
instrumental activities of daily living
IRB
Institutional Review Board

RR
relative risk
SD
standard deviation
SE
standard error.

Declarations

Ethics approval and consent to participate

CHARLS was approved by the Institutional Review Board of Peking University (IRB00001052-11015). All participants provided written informed consent.

Consent for publication

Not applicable.

Availability of data and materials

The CHARLS datasets analysed during the current study are publicly available to registered researchers at https://charls.pku.edu.cn.

Competing interests

The authors declare that they have no competing interests.

Clinical trial number: not applicable

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Authors' contributions

CL and HQL conceived and designed the study. WZ and SY performed the statistical analysis. CL drafted the manuscript. All authors interpreted the findings, revised the manuscript critically and approved the final version.

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Figures

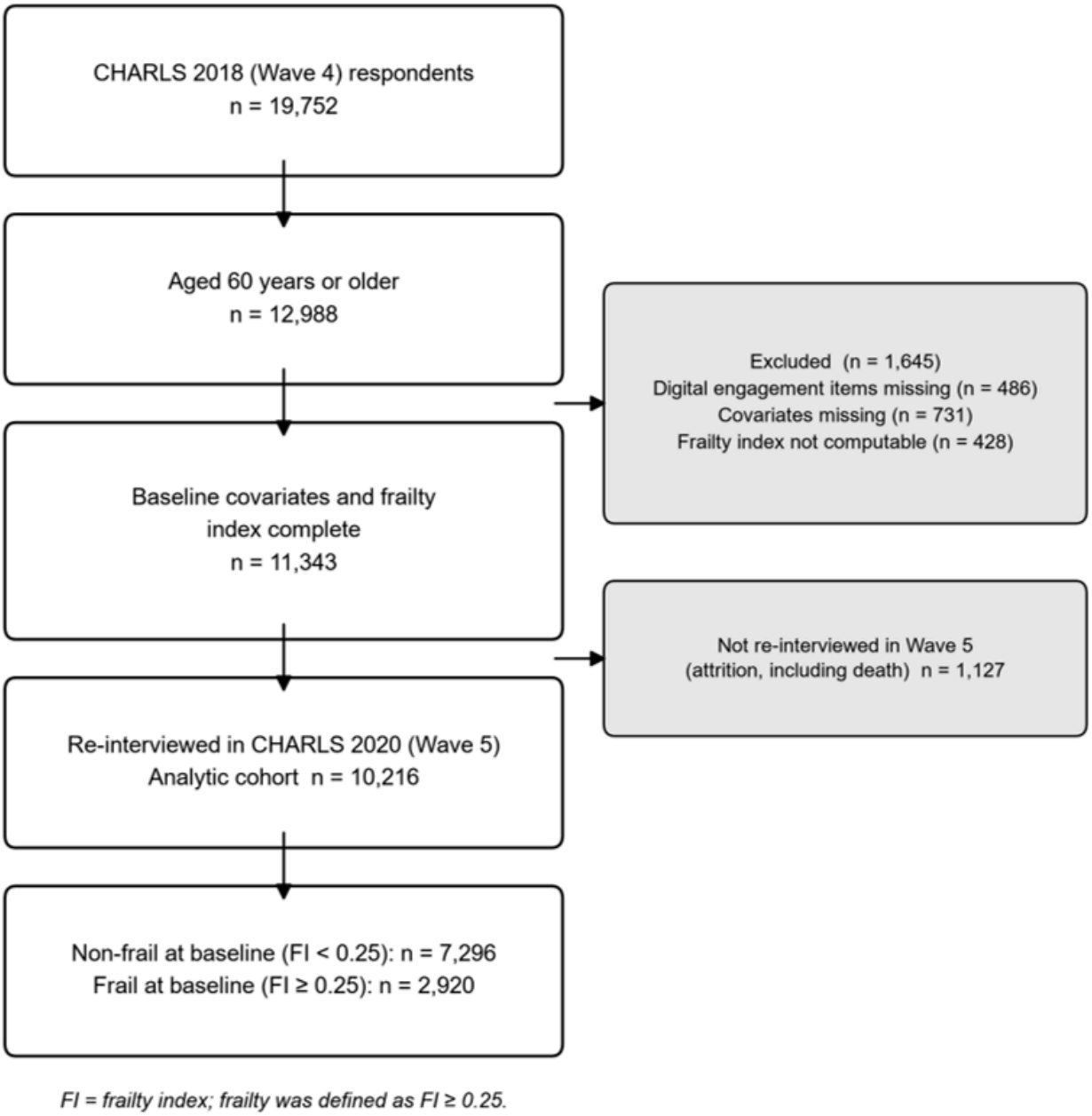


Figure 1

Flow of participants through the study, CHARLS 2018–2020.

note. CHARLS = China Health and Retirement Longitudinal Study; FI = frailty index.

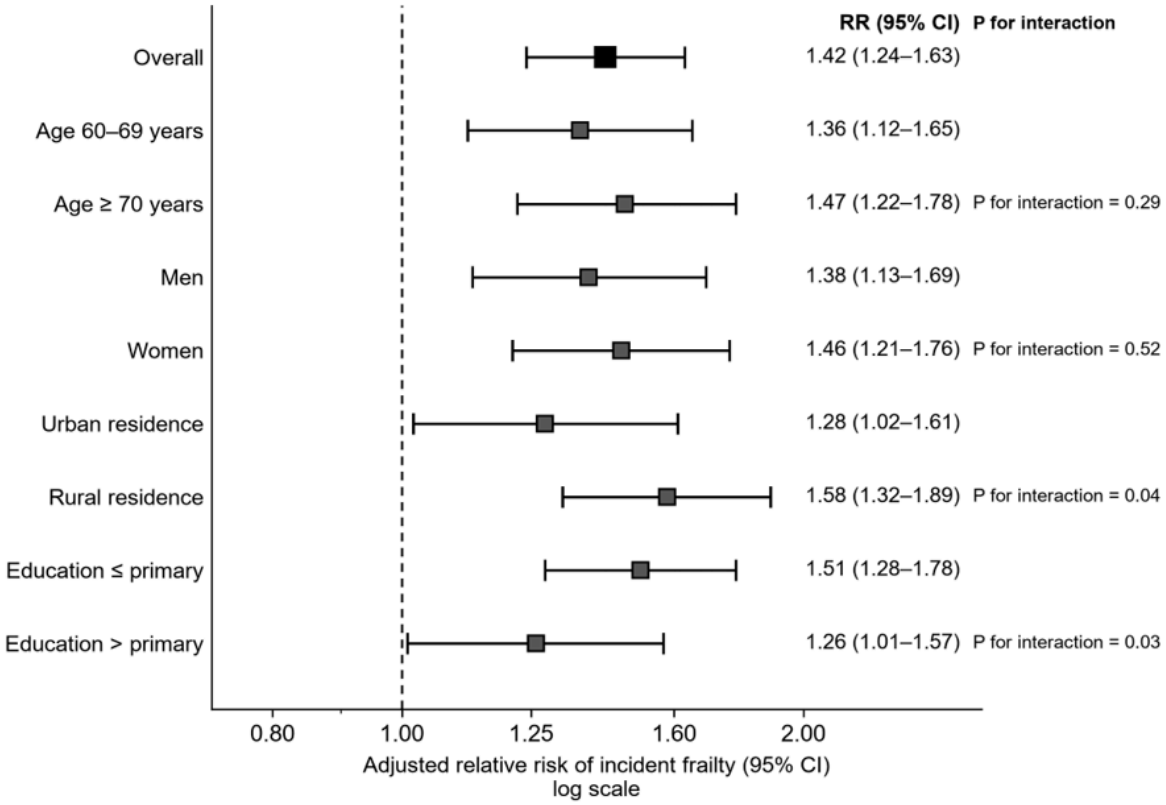


Figure 2

Subgroup analyses of the association between full digital exclusion and incident frailty.

Note. Adjusted relative risks (squares) with 95% confidence intervals (horizontal lines) are shown for each subgroup, from Model 3 (adjusted for age, sex, marital status, residence, region, education, working status, household wealth quintile, smoking, alcohol consumption, chronic conditions, social activity score and baseline frailty index). P values are for interaction.*RR = relative risk; CI = confidence interval. Models adjusted for age, sex, marital status, residence, region, education, working status, household wealth quintile, smoking, alcohol consumption, chronic conditions, social activity score and baseline frailty index.*