



# The long-term impact of childhood peer relationships on disability in later life: Causal mediation evidence from older Chinese adults

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## ABSTRACT

Despite the recognized importance of social connections in Chinese culture, research on how childhood peer relationship deficits impact health later in life has been limited. This study aimed to investigate the association between childhood peer relationship deficits and the odds of disability among older Chinese adults and to explore the potential mediating roles of social isolation, loneliness, and cognitive function. Using the longitudinal sample of respondents aged 60 years and older in the China Health and Retirement Longitudinal Study 2013–2018 ( $N = 7133$ ), the link between peer relationship deficits in childhood and disability in late life was assessed using marginal structural models, and the potential mediating effects of social isolation, loneliness, and cognitive function were examined by the inverse odds ratio weighting technique. Participants who experienced greater childhood peer relationship deficits were more prone to disability (odds ratio: 1.19, 95% CI: 1.09, 1.29) than those with more positive childhood peer interactions. The inverse odds ratio weighting analysis indicated that social isolation, loneliness, and cognitive function individually played partial mediating roles in the association between childhood peer relationships and disability by 11.36% (95% CI: 4.04%–18.99%), 11.95% (95% CI: 4.65%–19.23%), and 24.58% (95% CI: 17.01%–32.43%), respectively. The combined mediation effect of the three mediators was 30.57% (95% CI: 23.52%–39.91%). These findings suggest that interventions to enhance social connections and cognitive health in older adults may help mitigate the long-term impacts of childhood peer relationship deficits on disability among older Chinese adults.

## 1. Introduction

The increase in disability related to activities of daily living (ADL) is a pressing public health challenge, particularly considering China's rapidly aging population. Projections indicate that the number of older Chinese adults with disability could increase from approximately 45.30 million in 2020 to 59.32 million by 2030, increasing by more than 30% in a decade (Gong et al., 2022). This significant increase underscores the urgent need to identify modifiable risk factors and develop effective intervention strategies to mitigate the burden of disability on the quality of life of older adults and the health care system. Although existing research has been devoted to identifying modifiable risk factors in adulthood (Balzi et al., 2010; Guo et al., 2021; Raimo et al., 2024), a life-course perspective highlights the profound role of early-life social experiences, notably childhood peer relationships, in developing ADL disabilities later in life (Kuh et al., 2003).

In China, where communal relationships and a collectivistic society are highly valued, childhood peer interactions are fundamental to

individual well-being and social development (Chen et al., 2009). Early peer relationships are considered crucial for developing social skills, navigating social hierarchies, and internalizing cultural values, which promotes harmonious social interactions throughout life (Laursen and Mooney, 2005). However, despite the recognized importance of social connections in Chinese culture, limited research has investigated the long-term health effects of childhood peer relationships on the development of disability in late life. This gap is highly significant because it hinders the development of targeted interventions and policies that could mitigate the odds of disability by addressing early social adversities within the Chinese sociocultural context.

### 1.1. Theoretical framework

Childhood social relationships play a critical role in developmental trajectories that impact health and well-being across the lifespan. Our exploration draws upon three well-established life course models—latency, pathway, and accumulation—and articulates the

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mechanisms by which childhood peer relationships could impact the odds of disability (Ben-Shlomo et al., 2016). The latency model posits that childhood peer relationships have a direct and long-lasting impact on the odds of later-life disability, which may be explained by the concept of embodiment. This concept suggests that early life experiences can become biologically embedded and influence health trajectories (Hertzman, 1999). Peer relationship deficits in childhood, including infrequent participation in friend groups or a lack of close friendships, can trigger the body's stress response systems, which results in chronic inflammation and dysregulation of the hypothalamic–pituitary–adrenal (HPA) axis (Cacioppo & Hawkley, 2009). Over time, these physiological alterations can contribute to the development of chronic health conditions and accelerated aging processes, heightening the odds of functional impairment and disability in older adults (Franceschi & Campisi, 2014).

The pathway model posits that childhood peer relationships indirectly impact the odds of later-life disability through psychosocial pathways, such as social isolation, loneliness, and cognitive function (Kuh et al., 2003). First, drawing upon social network theory, which underscores the importance of social ties for health and well-being (Berkman & Glass, 2000), we argue that poor peer relationships in childhood can hinder the development of social skills and limit opportunities for building robust social networks, leading to social isolation in adulthood. Social isolation, in turn, increases the odds of disability by reducing access to practical support, emotional sustenance, and opportunities for social engagement, all of which are crucial for maintaining functional independence (Holt-Lunstad et al., 2010; Lai et al., 2024). Second, we draw upon attachment theory to explain the mediating role of loneliness (Bowlby, 1969). Early peer relationships, as a primary context for social interaction, contribute significantly to the development of attachment styles and social-emotional regulation. Negative peer experiences in childhood can foster insecure attachment styles characterized by difficulties in forming and maintaining close relationships and increased vulnerability to feelings of loneliness and social isolation later in life (Cacioppo & Hawkley, 2003). Chronic loneliness has been linked to a cascade of physiological and psychological consequences, including increased inflammation, impaired sleep, and a heightened risk of depression, all of which can contribute to functional decline and disability (Hawkley & Cacioppo, 2010; Qi et al., 2023). Finally, we incorporate a cognitive reserve perspective to explain how childhood peer relationships may influence disability through their impact on cognitive function. Engaging in social interactions, particularly during childhood and adolescence, provides rich opportunities for cognitive stimulation and promotes the development of cognitive reserve, which refers to the brain's capacity to cope with age-related neurological changes and resist cognitive decline (Stern, 2009). Positive peer interactions during childhood, characterized by communication, cooperation, and problem solving, can enhance cognitive reserve and protect against cognitive decline later in life. Conversely, limited or negative peer interactions can lead to cognitive understimulation and increase the risk of cognitive impairment, which is strongly associated with disability (Fratiglioni et al., 2004; Kong, Lu, Jiang, & Chan, 2024).

The cumulative model posits that disadvantages experienced throughout the life course accumulate and exacerbate health risks. This perspective is rooted in theories such as cumulative advantage/disadvantage theory (Dannefer, 2003) and cumulative inequality theory (Ferraro & Shippee, 2009). Building upon this model, we propose that negative childhood peer relationships, coupled with subsequent social and health challenges, create a cumulative burden that increases vulnerability to disability. These accumulated adversities heighten the risk of cognitive decline and disability in older age due to their persistent and expanding impact over time.

This study investigated the relationship between childhood peer relationships and the odds of disability later in life, aiming to answer two key questions: (1) How do childhood peer relationships affect the odds of disability later in life? (2) To what extent do social isolation,

loneliness, and cognitive function mediate this relationship? We hypothesize that negative childhood peer relationships can both directly and indirectly increase the odds of disability later in life through their detrimental impacts on social isolation, loneliness, and cognitive function. To rigorously examine these hypothesized pathways, we used marginal structural modeling to estimate the causal association between peer relationships in childhood and disability, addressing potential confounding and selection bias inherent in observational data (Hernan et al., 2000). Additionally, we employed inverse odds ratio weighting (IORW) to estimate the potential mediating roles of social isolation, loneliness, and cognitive function, further clarifying the indirect pathways linking early social experiences to functional health later in life (Nguyen et al., 2015). Fig. 1 provides a visual representation of the hypothesized causal pathways, offering comprehensive insight into the complex relationships under investigation.

## 2. Methods

### 2.1. Study sample and data collection

This retrospective cohort study leveraged data from the China Health and Retirement Longitudinal Study (CHARLS), a nationally representative longitudinal survey that captures information on Chinese adults aged 45 and older. The CHARLS employs a multistage random probability sampling design with a probability proportional to size. Data on demographics, health, socioeconomic status, and childhood experiences were collected via structured questionnaires and face-to-face interviews conducted every two years beginning in 2011. Detailed information on the CHARLS methodology has been published previously (Zhao et al., 2014).

The present study-utilized data from Wave 2 (CHARLS 2013) as the baseline, with follow-up data spanning through 2018. We applied a series of exclusion criteria to the initial cohort of 18,610 eligible participants at the baseline. First, participants aged younger than 60 years in 2018 were excluded ( $n = 6284$ ). Furthermore, we omitted participants who were lost to follow-up or who died between 2014 and 2018 ( $n = 2394$ ), as well as those who experienced disabilities in 2015 ( $n = 1964$ ). Finally, participants with missing data on crucial variables, including exposure, mediators, and outcome, were excluded ( $n = 835$ ). The resulting analytical sample for the current study consisted of 7133 individuals. Sampling weights were applied to generate nationally representative estimates.

### 2.2. Measures

#### 2.2.1. Outcome

Disability was assessed in 2018 using a combined measure of basic

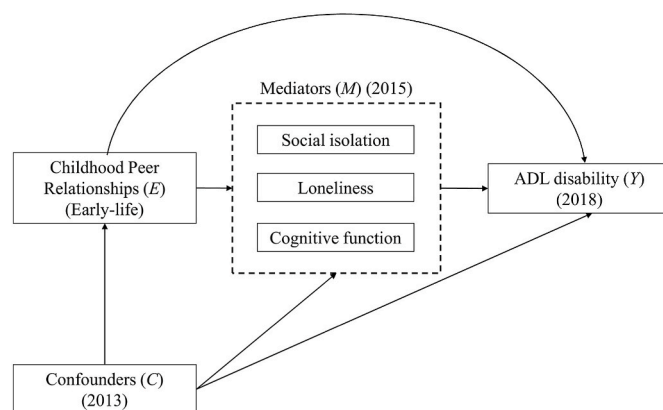


Fig. 1. Directed acyclic graph illustrating the proposed mediating pathways linking early-life peer relationships to disability later in life.

ADL (BADL) and instrumental ADL (IADL) limitations (Zajacova & Montez, 2018). BADLs encompass six essential self-care tasks: eating, dressing, bathing, transferring in and out of bed, toileting, and continence management (Katz et al., 1963). IADLs include the ability to perform tasks necessary for independent living, including managing finances, making phone calls, housekeeping, meal preparation, medication management, and shopping (Guo et al., 2021). Disability was defined as needing help or being unable to perform at least one activity within either the BADL or IADL domain. This combined measure provides a comprehensive assessment of functional impairment, capturing limitations in both basic self-care and complex tasks required for independent community living.

### 2.2.2. Exposure

Childhood peer relationships were assessed using a summary index derived from the 2014 Life History Survey (Chen et al., 2021). This index (range 0–3) was constructed from three items measuring peer relationship status before age 17: (1) frequency of loneliness due to lack of friends, (2) frequency of having a group of friends, and (3) presence of good friends. The first two items were assessed on a four-point Likert scale (never, not very often, sometimes, often) and dichotomized. Loneliness due to lack of friends was coded as 0 for "never" or "not very often" and 1 for "sometimes" or "often". Having a group of friends was coded as 0 for "sometimes" or "often" and 1 for "never" or "not very often". Presence of a good friend was coded as 0 for "yes" and 1 for "no". Higher scores on the index reflect poorer childhood peer relationships (Burr et al., 2020; Xie et al., 2022).

### 2.2.3. Mediators

The mediators, including social isolation, loneliness, and cognitive function, were all measured during Wave 4 (2015), which maintained the correct temporal ordering of data (exposure-mediator-outcome) for our causal mediation analysis. Social isolation was assessed using a five-point index (range 0–5) based on five indicators: (1) marital status (unmarried or not cohabiting), (2) infrequency of contact with children (less than once per month through face-to-face interactions, telephone calls, or email/written correspondence), (3) infrequency of contact with other family members, (4) infrequency of interaction with friends, and (5) lack of involvement in various organizations, such as sports groups, community clubs, social clubs, volunteering activities, or charitable organizations. Higher scores reflect greater social isolation. Consistent with prior research, participants were categorized as socially connected (scores 0–1) or socially isolated (scores 2–5) (Smith et al., 2021).

Loneliness was assessed using a single-item measure of self-reported frequency of feeling lonely. Responses were dichotomized, with "rarely" or "a little of the time" coded as 0 and "a moderate amount" or "most of the time" coded as 1. Despite the limitations of single-item measures for capturing the complexity of loneliness, this approach is common in large-scale studies and has demonstrated validity and reliability in previous research (Victor et al., 2005).

**Cognitive Function:** Cognitive function was assessed using a composite score derived from two indicators: episodic memory and mental intactness. Episodic memory was measured using a 10-word recall task that involved both immediate and delayed recall components, yielding scores on a scale from 0 to 10. Mental intactness was assessed using a three-item battery comprising serial subtraction (counting down from 100 in increments of 7), orientation to time (naming the day, date, month, year, and season), and visual memory (redrawing a figure from memory). Scores on the mental intactness battery ranged from 0 to 11. A composite cognitive function score was calculated by summing the scores of the two indicators, resulting in a range of 0–21 (Xu et al., 2018). For analysis, this continuous score was dichotomized based on the mean, with participants classified as having low cognitive function (1) or high cognitive function (0). This dichotomization allows the mediating role of cognitive function within the causal pathway to be interpreted.

### 2.2.4. Confounders

To mitigate the influence of potential confounding variables on the relationship between childhood peer relationships and disability, we included a comprehensive set of time-invariant and time-varying confounders in our analyses. The time-invariant confounders included sociodemographic characteristics, assessed at baseline (2013), included age (years), gender (man or woman), educational attainment (illiterate, elementary school, middle school or higher), and ethnicity (Han or other).

The time-varying confounders included socioeconomic factors, health behaviors, and health-related factors. The socioeconomic factors included dwelling type (urban or rural), present employment conditions (unemployed or employed), and per capita household expenditures (continuous or log-transformed). Health behaviors included smoking status (never smokers, former smokers, and current smokers), alcohol consumption (never drinkers, past drinkers, and current drinkers), and nightly sleep duration (hours). Health-related factors included health insurance coverage (insured or uninsured), hearing problems (presence or absence), and the presence of chronic illnesses (defined as the presence or absence of any of the fourteen conditions, including stroke, heart disease, arthritis or rheumatism, memory-related disease, chronic lung diseases, etc.).

### 2.3. Statistical analyses

We summarized participant characteristics using descriptive statistics. Continuous variables were compared using ANOVAs, and categorical variables were compared using  $\chi^2$  tests. To estimate the association between childhood peer relationships and the odds of disability, we employed a two-stage marginal structural modeling (MSM) approach. First, we used inverse probability weighting (IPW) to construct a pseudopopulation in which time-varying confounders were balanced across different levels of childhood peer relationships. For censoring ( $C$ ), exposure ( $A$ ), and mediators ( $M$ ), separate IPWs were computed as follows:

$$IPW_i^C = \frac{P(C=0|A=a, F=f_i)}{P(C=0|A=a_i, F=f_i, L=l_i)} \quad (1)$$

$$IPW_i^A = \frac{P(A=a_i|F=f_i)}{P(A=a_i|F=f_i, L=l_i)} \quad (2)$$

$$IPW_i^M = \frac{P(M=m_i|A=a_i, F=f_i)}{P(M=m_i|A=a_i, F=f_i, L=l_i)} \quad (3)$$

where  $C=0$  indicates uncensored subjects and IPWs for censoring were included to address censoring in the MSM.  $A$  represents childhood peer relationships,  $M$  represents each mediator (social isolation, loneliness, or low cognitive function),  $F$  denotes time-invariant confounders, and  $L$  denotes time-varying confounders. IPWs for censoring were adjusted for censoring in the MSM. We truncated the weights at the 1st and 99th percentiles to create stabilized weights (SWs) for improved stability (Cole & Hernan, 2008).

Subsequent analyses consisted of three core evaluations: the association of childhood peer relationships with disability (weighted by  $SW_E = SW_i^C \times SW_i^F$ ), the association of childhood peer relationships with mediators (weighted by  $SW_E$ ), and the association of mediators with disability (weighted by  $SW_{EM} = SW_i^C \times SW_E$ ). These were quantified by the following:

$$\text{logit } p(Y=1|A=a, F=f) = \alpha_0 + \alpha_1 A + \alpha_2 f \quad (4)$$

$$\text{logit } p(M=1|A=a, F=f) = \beta_0 + \beta_1 A + \beta_2 f \quad (5)$$

$$\text{logit } p(Y=1|A=a, M=m, F=f) = \gamma_0 + \gamma_1 A + \gamma_2 M + \gamma_3 f \quad (6)$$

where  $Y$  represents disability. In summary, the three core evaluations

described above, along with the application of appropriate weighting techniques, form the foundation of our robust analytical approach to investigating the complex relationships between childhood peer relationships, social isolation, loneliness, cognitive function, and disability later in life.

We employed the IORW technique to examine the potential mediating roles of social isolation, loneliness, and cognitive function. This approach enabled the decomposition of the total effect into natural direct effects (NDEs) and natural indirect effects (NIEs) among multiple mediators. The inclusion of multiple mediators in our study highlights the importance of using the IORW method to isolate and examine the specific contributions of each mediator to the association of early-life peer relationships with the odds of disability. By employing this approach, we can gain a more nuanced understanding of how social isolation, loneliness, and cognitive function may differentially play mediating roles in the association between early-life social experiences and disability in older Chinese adults. IORW weights, derived by inverting the odds ratios of the association between childhood peer relationships and each mediator with adjustment for confounders, were then applied in logistic regression models to isolate the NDEs of childhood peer relationships on the odds of disability, effectively removing the influence of the mediators. The NIEs were subsequently calculated by taking the difference between the total effect and the NDE. To quantify the relative contribution of indirect effects, we calculated the mediating proportion by dividing the NIE by the total effect. The confidence intervals (CIs) for all the coefficients were estimated by bootstrapping with 1000 replications. The latency model is supported by a significant NDE coefficient, indicating a lasting effect of early-life social contexts on later functioning. Significant NIEs demonstrate indirect effects via psychosocial pathways, supporting the pathway model and the cumulative model, which may operate concurrently.

To assess the robustness of our findings, we performed sensitivity analyses. First, to address potential bias due to unobserved confounding, E-values were calculated to quantify the magnitude of unobserved confounding necessary to explain the observed associations. Second, we evaluated the sensitivity to extreme weights by implementing broader truncation ranges for the IPWs (1st/99th and 10th/90th percentiles).

We addressed missing data in our longitudinal analysis using a combination of strategies. For missing mediator and outcome data, we employed the last observation carried forward approach. Missing confounder data were handled using multiple imputation. Statistical analyses were performed using Stata version 16.0 (StataCorp; College Station, TX).

### 3. Results

Table 1 presents the characteristics of the 7133 participants in our study. Approximately 51% were male, 93% were Han Chinese, and 27% had attained at least a junior high school education. The prevalence of childhood peer relationship deficits varied, with 2727 (38.2%) participants reporting no deficits and 336 (4.7%) reporting experiences across all three peer relationship deficits. Participants who experienced poor peer relationships in childhood were more likely to exhibit a constellation of characteristics, including reduced educational achievement, residence in rural areas, current employment, and having hearing problems. Furthermore, they were more likely to experience social isolation, loneliness, lower cognitive function, and disability. The weighted distribution of time-varying confounders across the different levels of childhood peer relationships is presented in Supplemental Table 1. The results are balanced across various levels of peer relationships in childhood.

Table 2 presents the causal associations between childhood peer relationships and disability, along with the mediating effects of social isolation, loneliness, and low cognitive function, estimated using MSM. In Model 1, childhood peer relationship deficits were associated with 19% increased odds of disability (OR = 1.19, 95% CI: 1.09–1.29). This

**Table 1**

Characteristics of participants according to childhood peer relationships in the analytic sample ( $N = 7133$ ).

Characteristic	Childhood peer relationships, No. (%)					P value
	Total	0 (n = 2727)	1 (n = 2570)	2 (n = 1500)	3 (n = 336)	
Age group						<0.001
60-69	4446 (62.33)	1810 (66.37)	1591 (61.91)	849 (56.60)	196 (58.33)	
70-79	2102 (29.47)	734 (26.92)	771 (30.00)	495 (33.00)	102 (30.36)	
80+	585 (8.20)	183 (6.71)	208 (8.09)	156 (10.40)	38 (11.31)	
Men	3676 (51.54)	1372 (50.31)	1380 (53.70)	745 (49.67)	179 (53.27)	0.03
Ethnic Han	6652 (93.26)	2513 (92.15)	2392 (93.07)	1431 (95.40)	316 (94.05)	<0.001
Education						
Non-literate	2014 (28.23)	587 (21.53)	671 (26.11)	614 (40.93)	142 (42.26)	<0.001
Elementary school	3137 (43.98)	1102 (40.41)	1211 (47.12)	670 (44.67)	154 (45.83)	
Middle school or higher	1982 (27.79)	1038 (38.06)	688 (26.77)	216 (14.40)	40 (11.90)	
Rural residence	5526 (77.47)	1900 (69.67)	2021 (78.64)	1300 (86.67)	305 (90.77)	<0.001
Current working	4882 (68.44)	1741 (63.84)	1807 (70.31)	1080 (72.00)	254 (75.60)	<0.001
Log-transformed income <sup>a</sup>	8.39 (2.49)	8.58 (2.37)	8.33 (2.54)	8.22 (2.50)	8.02 (2.81)	<0.001
Smoking status						
Nonsmoker	3841 (53.85)	1491 (54.68)	1350 (52.53)	814 (54.27)	186 (55.36)	0.25
Former smoker	518 (7.26)	216 (7.92)	184 (7.16)	97 (6.47)	21 (6.25)	
Current smoker	2774 (38.89)	1020 (37.40)	1036 (40.31)	589 (39.27)	129 (38.39)	
Drinking status						
Nondrinker	3780 (52.99)	1417 (51.96)	1352 (52.61)	823 (54.87)	188 (55.95)	0.11
Former drinker	776 (10.88)	315 (11.55)	257 (10.00)	162 (10.80)	42 (12.50)	
Current drinker	2577 (36.13)	995 (36.49)	961 (37.39)	515 (34.33)	106 (31.55)	
Sleep duration (hours) <sup>a</sup>	6.17 (1.80)	6.21 (1.70)	6.20 (1.81)	6.10 (1.91)	5.97 (2.00)	<0.001
Medical insurance	6917 (96.97)	2642 (96.88)	2500 (97.28)	1451 (96.73)	324 (96.43)	0.68
Hearing problems	477 (6.69)	153 (5.61)	169 (6.57)	120 (8.00)	35 (10.42)	<0.001
Having chronic conditions	5213 (73.08)	1963 (71.98)	1891 (73.58)	1097 (73.13)	262 (77.98)	0.11
Social isolated	3716 (52.10)	1165 (42.72)	1373 (53.42)	963 (64.20)	215 (63.99)	<0.001
Lonely	1121 (15.72)	362 (13.27)	387 (15.06)	287 (19.13)	85 (25.30)	<0.001
Low Cognition	3698 (51.84)	1124 (41.22)	1332 (51.83)	1014 (67.60)	228 (67.86)	<0.001
Disabled	1165 (16.33)	353 (12.94)	436 (16.96)	303 (20.20)	73 (21.73)	<0.001

<sup>a</sup> Mean (SD).

association remained significant after sequentially adjusting for social isolation (Model 2; OR = 1.18, 95% CI: 1.08–1.28), loneliness (Model 3; OR = 1.18, 95% CI: 1.08–1.28), and low cognitive function (Model 4; OR = 1.15, 95% CI: 1.05–1.25). Models 2, 3, and 4 revealed that social isolation (OR = 1.22, 95% CI: 1.04–1.43), loneliness (OR = 1.30, 95% CI: 1.07–1.59), and low cognitive function (OR = 1.83, 95% CI: 1.51–2.22) were each independently associated with increased odds of disability. When both social isolation and loneliness were included in the model (Model 5), the association between childhood peer relationship deficits and disability was slightly attenuated (OR = 1.17, 95% CI:



**Table 2**Association of childhood peer relationships with disability and mediating effects among Chinese older adults: MSM ( $N = 7133$ ).

Variable	Odds Ratio (95% CI) <sup>a</sup>					
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Childhood peer relationships	1.19 (1.09,1.29)	1.18 (1.08,1.28)	1.18 (1.08,1.28)	1.15 (1.05,1.25)	1.17 (1.07,1.27)	1.14 (1.04,1.25)
Social isolation	–	1.22 (1.04,1.43)	–	–	1.23 (1.05,1.45)	1.18 (1.00,1.40)
Loneliness	–	–	1.30 (1.07,1.59)	–	1.32 (1.08,1.62)	1.26 (1.02,1.56)
Low cognitive function	–	–	–	1.83 (1.51,2.22)	–	1.75 (1.43,2.15)
Age	1.77 (1.59,1.98)	1.78 (1.58,1.99)	1.79 (1.60,2.00)	1.75 (1.57,1.96)	1.79 (1.60,2.01)	1.78 (1.59,2.00)
Men	0.75 (0.63,0.88)	0.76 (0.64,0.91)	0.76 (0.64,0.90)	0.74 (0.62,0.87)	0.78 (0.65,0.92)	0.76 (0.64,0.91)
Ethnic Han	0.72 (0.55,0.95)	0.72 (0.55,0.95)	0.72 (0.55,0.96)	0.72 (0.55,0.95)	0.73 (0.54,0.96)	0.72 (0.54,0.96)
Education	0.69 (0.62,0.77)	0.71 (0.64,0.80)	0.69 (0.62,0.77)	0.84 (0.74,0.95)	0.72 (0.64,0.80)	0.86 (0.75,0.98)

Notes: MSM = marginal structural models.

<sup>a</sup> Stabilized weights accounted for residence, current working, income, smoking, drinking, sleep duration, medical insurance, hearing problems, having chronic conditions.

1.07–1.27). Further adjusting for low cognitive function in Model 6 revealed a slightly weaker association between childhood peer relationship deficits and disability (OR = 1.14, 95% CI: 1.04–1.25). The associations between each mediator and disability remained statistically significant. According to all the models, older age, female, ethnic minority, and lower education were associated with a greater odds of disability in older adults. Furthermore, individuals with childhood peer relationship deficits were more likely to experience social isolation (OR = 1.35, 95% CI: 1.26–1.44), loneliness (OR = 1.18, 95% CI: 1.08–1.28) and diminished cognitive functioning (OR = 1.31; 95% CI: 1.21–1.41) (Supplemental Table 2).

Table 3 presents the mediating effects of social isolation, loneliness, and low cognitive function on the link between peer relationships in childhood and disability, estimated using IORW. Examining individual mediators, social isolation and loneliness had NIEs of 1.02 each, translating into mediation proportions of 11.36% (95% CI: 4.04%, 18.99%) and 11.95% (95% CI: 4.65%, 19.23%), respectively. Notably, cognitive function exhibited a more substantial NIE of 1.04 (95% CI: 1.03, 1.06), corresponding to an impressive mediation proportion of 24.58% (95% CI: 17.01%, 32.43%). Including both social isolation and loneliness as mediators explained 14.67% (95% CI: 7.24%, 22.53%) of the total effect. When all three mediators were considered simultaneously, the combined mediating proportion increased to 30.57% (95% CI: 23.52%, 39.91%). The NDEs remained statistically significant in all models, ranging from 1.13 (95% CI: 1.10, 1.15) to 1.16 (95% CI: 1.14, 1.19). This finding suggested an independent influence of childhood peer relationships on disability, even after individually and collectively accounting

for each mediator.

According to our sensitivity analysis, the associations between childhood peer relationships and disability, as mediated by social isolation, loneliness, and low cognitive function, remained robust despite the application of varying weight truncation values (Supplemental Table 3). Additionally, the E-values for childhood peer relationships varied minimally across our models, from 1.54 to 1.67, reflecting moderate robustness against unmeasured confounding variables. Compared to childhood peer relationships, variables related to social isolation, loneliness, and cognitive function in adulthood showed greater resilience to unmeasured confounders, suggesting their potentially stronger impact on the odds of disability (Supplemental Table 4).

#### 4. Discussion

This study provides novel insights into the enduring impact of early social experiences on later-life health by examining the causal pathways that link childhood peer relationship deficits to disability in older Chinese adults. Utilizing data from the CHARLS and employing robust causal mediation analyses via MSM and IORW, we found that childhood peer relationship deficits significantly increase the odds of disability later in life, even after rigorously adjusting for a comprehensive set of potential confounders. Specifically, our analysis revealed that this association was significantly mediated by social isolation, loneliness, and low cognitive function in adulthood. These findings highlight the multifaceted and potentially cumulative detrimental impact of early social adversity on later-life functional health.

Our findings contribute to the growing body of literature that documents the enduring impact of early social experiences on later-life health, but they uniquely highlight the direct and persistent effect of childhood peer relationships on disability in older Chinese adults. While previous research has established links between early adversity and various health outcomes (Hertzman & Power, 2006; Miller et al., 2011), our study specifically indicates a robust association with functional limitations in later life, even after accounting for multiple mediating pathways and utilizing MSM to mitigate potential biases arising from time-varying confounders. This direct effect, which lends support to the latency model, suggests that early adverse social experiences may trigger a cascade of physiological consequences that accumulate over the life course, ultimately increasing vulnerability to disability. This direct effect can be explained by the concept of embodiment, which suggests that early life experiences can become biologically embedded and influence health trajectories (Hertzman, 1999). For instance, exposure to limited peer interactions during childhood can activate chronic stress responses, leading to the dysregulation of the HPA axis and elevated cortisol levels (Shonkoff et al., 2012). This chronic physiological stress can contribute to systemic inflammation, accelerated cellular aging, and impaired immune function, increasing the risk for chronic conditions such as cardiovascular disease and arthritis (Danese & McEwen, 2012; Miller et al., 2011). Our study underscores the

**Table 3**Mediating effects of social isolation, loneliness and cognitive function on the association between childhood peer relationships and adult disability: IORW ( $N = 7133$ ).

Mediators	Odds Ratio (95% CI) <sup>a</sup>			Mediation proportion % (95% CI) <sup>b</sup>
	TE	NDE	NIE	
Social Isolation (M <sub>1</sub> )	1.19 (1.16, 1.21)	1.16 (1.14, 1.19)	1.02 (1.01, 1.03)	11.36 (4.04, 18.99)
Loneliness (M <sub>2</sub> )	1.19 (1.16, 1.21)	1.16 (1.14, 1.19)	1.02 (1.01, 1.03)	11.95 (4.65, 19.23)
Cognitive Function (M <sub>3</sub> )	1.19 (1.16, 1.21)	1.14 (1.12, 1.16)	1.04 (1.03, 1.06)	24.58 (17.01, 32.43)
M <sub>1</sub> + M <sub>2</sub>	1.19 (1.16, 1.21)	1.16 (1.13, 1.18)	1.03 (1.01, 1.04)	14.67 (7.24, 22.53)
M <sub>1</sub> + M <sub>2</sub> + M <sub>3</sub>	1.19 (1.16, 1.21)	1.13 (1.10, 1.15)	1.05 (1.04, 1.07)	30.57 (23.52, 39.91)

Notes: IORW = inverse odds ratio weighted models; TE, total effect; NDE, natural direct effects; NIE, natural indirect effects.

<sup>a</sup> Stabilized weights accounted for residence, current working, income, smoking, drinking, sleep duration, medical insurance, hearing problems, having chronic conditions.<sup>b</sup> Calculated as  $[NIE/(NDE + NIE)] \times 100\%$ .

importance of fostering positive social relationships in childhood to mitigate long-term health risks and enhance functional independence in older individuals.

Beyond direct effects, our study went further to unpack the pathways by which childhood peer relationship deficits might lead to disability, specifically examining the mediating roles of social isolation, loneliness, and low cognitive function. These factors individually and collectively mediated a significant portion of the relationship between childhood peer relationship deficits and disability, emphasizing the complexity of the pathway from early social adversity to later-life functional impairment. These findings support the pathway and cumulative models of life-course determinants, highlighting that early social adversities contribute to a chain of risks culminating in later-life functional disabilities.

Our results indicate that individuals who experienced peer relationship deficits in childhood were more likely to struggle with establishing and maintaining social connections in adulthood, leading to increased social isolation – defined as an objective lack of social contact (Hawkey & Cacioppo, 2010). This finding aligns with previous research demonstrating that early social difficulties can have lasting effects on social development, increasing the risk of social withdrawal and limited social networks later in life (Newcomb et al., 1993). Importantly, social isolation itself can contribute to a cascade of adverse health outcomes that increase the odds of disability (Nakagomi et al., 2023). Socially isolated individuals are at heightened risk of adopting detrimental health-related behaviors, such as suboptimal nutritional intake and a sedentary lifestyle, which are linked to chronic diseases and functional decline (Cacioppo et al., 2002). Moreover, social isolation can limit access to practical support, including assistance with daily tasks and caregiving, further increasing vulnerability to functional decline and disability (Cornwell & Waite, 2009).

Beyond objective social isolation, our study also identified loneliness—a subjective feeling of being alone or disconnected, regardless of actual social contact (Holt-Lunstad et al., 2015)—as a key mediator in the relationship between childhood peer difficulties and disability. This finding supports the role of attachment theory in explaining the mediating role of loneliness (Bowlby, 1969). Our results suggest that individuals who experienced adverse peer relationships in childhood are more likely to report feeling lonely in adulthood, even if they have objective social connections. Loneliness has been linked to a spectrum of adverse health consequences, including elevated risks of cardiovascular disease and depression, ultimately contributing to the development of chronic health conditions and accelerated aging processes that increase the odds of disability in older adulthood (Cacioppo & Hawkey, 2009; Franceschi & Campisi, 2014; Hertzman, 1999). This relationship underscores the importance of considering both objective and subjective measures of social connection when examining the long-term health consequences of early social adversity (Akhter-Khan et al., 2024).

Furthermore, our findings suggest that early social adversity may have long-term consequences for cognitive function, which, in turn, can increase the odds of disability. This association may be explained by the cognitive reserve perspective, which posits that children who experience peer relationship deficits may face challenges in developing social skills, emotional regulation, and coping mechanisms, which are essential for navigating social situations and building healthy relationships (Rudolph et al., 2014). These early challenges can have cascading effects, potentially leading to reduced social engagement, cognitive inactivity, and increased stress throughout life, which ultimately contribute to cognitive decline in later years (Decker et al., 2007; Ding & He, 2021; Rudolph et al., 2014). Cognitive functions such as memory, executive function, and problem-solving skills are crucial for maintaining independence, and deficits in these areas can severely compromise ADL capabilities (Fratiglioni et al., 2004; Stern, 2009).

These findings are particularly relevant in China, where social harmony and strong family ties are highly valued (Chen et al., 2009). Childhood peer interactions in China, a collectivist society, are

fundamental in shaping social development and individual well-being (Chen et al., 2009). These early relationships are pivotal for developing essential social skills, navigating social hierarchies, and internalizing cultural values that emphasize harmonious social interactions (B. Laursen & Mooney, 2008). Our study underscores the profound implications of childhood peer difficulties, indicating that such adversities can disrupt social development and significantly increase the odds of isolation, loneliness, and cognitive decline later in life. This evidence highlights the need for a multifaceted approach to promote positive peer relationships and social skills development during childhood within Chinese society.

This study is not without limitations. First, the inherent assumptions of MSM approaches, particularly those regarding unmeasured confounders (interchangeability) and correct model specifications, warrant careful consideration when interpreting the findings (Cole & Hernan, 2008; Vanderweele & Arah, 2011). While the E-value sensitivity analyses imply that a moderate association between unmeasured confounding variables and both the exposure and outcome might sufficiently explain the relationship observed in the study, the potential for residual confounding cannot be entirely dismissed. Second, although the mean values of the estimated stabilized weights approach one, which suggests that the positivity assumption is fulfilled, violations of this assumption must be acknowledged. In this study, such violations are addressed by weight truncation, which introduces a trade-off between bias reduction and increased variance (Cole & Hernan, 2008). Third, while retrospective assessments of childhood experiences may be subject to recall bias, the reliability of such measures has been demonstrated in prior research, supporting their utility while advocating for prospective investigations to mitigate potential limitations (Baldwin et al., 2019). Fourth, the measure of disability is limited by its reliance on self-reporting, which may not completely capture long-term functional decline. Similarly, our study's measure of IADL disability is constrained by the CHARLS dataset, which does not include laundry and transportation tasks, potentially leading to an underestimation of IADL disability prevalence. Furthermore, our study may not fully account for gender differences in IADL tasks, as uniform criteria were applied to both men and women. Despite these limitations, self-reported ADL assessments are considered reliable and valid for evaluating functional limitations in older adults (Katz et al., 1963) and is widely utilized in epidemiological research (Syddall et al., 2009). Future research should employ datasets with comprehensive IADL evaluations. Fifth, although we used natural direct and indirect effects to isolate latency, pathway, and cumulative models, the single measurement of childhood peer relationships from CHARLS limits our capture of cumulative dynamics. Unobserved mechanisms may also intersect with these frameworks. Longitudinal studies with repeated measures of exposure are needed to better differentiate these models and their contributions to later-life functioning. Finally, the causal pathway between childhood peer relationships and disability in late life is likely complex and potentially involves unexplored mediators, including physiological processes (Crosnoe, 2000), which highlights avenues for future research.

In conclusion, our study highlights the complex interplay between childhood peer relationships, social isolation, loneliness, cognitive function, and disability in the Chinese context. The findings provide a comprehensive understanding of the mechanisms linking early social experiences to later-life functional health. This study emphasizes the importance of considering the unique sociocultural context of China when examining the long-term health consequences of childhood peer relationships. Interventions targeting social isolation, loneliness, and cognitive engagement are essential for mitigating these risks. Maintaining supportive social networks and promoting cognitive stimulation throughout life can potentially buffer the adverse impacts of poor childhood social experiences. Future research should focus on developing culturally sensitive interventions that address early social adversities and promote positive peer relationships to mitigate the odds of disability in older adults.

## CRedit authorship contribution statement

**Zi Zhou:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Feiyu Wang:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Formal analysis, Data curation.

## Role of the funding source

The funder had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

## Data statement

This study was based on publicly available data from the China Health and Retirement Longitudinal Study dataset (data available at: <https://charls.pku.edu.cn/en/>).

## Ethical statement

The Institutional Review Board of Peking University has approved the CHARLS, and all participants gave informed consent. This study, a secondary analysis using publicly available data sets (<http://charls.pku.edu.cn/>), was exempt from additional review. No identifiable personal information was accessed during this research. There are no conflicts of interest to declare.

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## 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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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.ssmph.2024.101735>.

## Data availability

Data will be made available on request.

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