

Digital Engagement and Cognitive Function Among Older Adults in China: Cross-Sectional Questionnaire Study and Moderated Mediation Model Analysis

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Abstract

Background: Given the global demographic shifts and rapid digitalization, digital engagement has emerged as a critical determinant of healthy aging. While previous research has linked digital engagement to cognitive outcomes, the underlying mechanisms remain underexplored among Chinese older adults.

Objective: On the basis of the technological reserve hypothesis, this study aimed to investigate a moderated mediation model linking digital engagement to cognitive function among older adults in China, with digital health literacy and social support as mediators and living arrangements as the moderator.

Methods: We conducted a cross-sectional questionnaire survey using stratified multistage sampling from June to November 2024, including 8123 participants. The eHealth Literacy Scale, the Perceived Social Support Scale and the Mini-Cog test were utilized to assess digital health literacy, social support and cognitive function. Mediation and moderated mediation analyses were performed using the PROCESS macro in SPSS with 5000 bootstrap resamples, adjusting for sociodemographic and health covariates.

Results: Higher digital engagement was associated with better cognitive function. Both digital health literacy and social support served as significant mediators in the relationship. Additionally, living arrangements moderated the associations of digital engagement with cognitive function, digital health literacy, and social support. These effects were stronger among older adults living alone.

Conclusions: The study highlights the complex interplay among digital engagement, cognitive function, and psychosocial factors, emphasizing the significant mediating effects of digital health literacy and social support. Living arrangements emerged as a key moderator, with digital engagement having a stronger influence on cognitive function among older adults living alone, underscoring the need for tailored interventions in this vulnerable group. Importantly, the findings suggest that digital technology use can be an effective strategy to mitigate cognitive decline in later life, emphasizing that interventions need to go beyond access and foster capacities to obtain digital information resources and leverage social support.

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Original Manuscript

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Digital Engagement and Cognitive Function Among Older Adults in China: Cross-Sectional Questionnaire Study and Moderated Mediation Model Analysis

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Abstract

Background

Given the global demographic shifts and rapid digitalization, digital engagement has emerged as a critical determinant of healthy aging. While previous research has linked digital engagement to cognitive outcomes, the underlying mechanisms remain underexplored among Chinese older adults.

Objective:

On the basis of the technological reserve hypothesis, this study aimed to investigate a moderated mediation model linking digital engagement to cognitive function among older adults in China, with digital health literacy and social support as mediators and living arrangements as the moderator.

Methods

We conducted a cross-sectional questionnaire survey using stratified multistage sampling from June to November 2024, including 8123 participants. The eHealth Literacy Scale, the Perceived Social Support Scale and the Mini-Cog test were utilized to assess digital health literacy, social support and cognitive function. Mediation and moderated mediation analyses were performed using the PROCESS macro in SPSS with 5000 bootstrap resamples, adjusting for sociodemographic and health covariates.

Results

Higher digital engagement was associated with better cognitive function. Both digital health literacy and social support served as significant mediators in the relationship. Additionally, living arrangements moderated the associations of digital engagement with cognitive function, digital health literacy, and social support. These effects were stronger among older adults living alone.

Conclusions

The study highlights the complex interplay among digital engagement, cognitive function, and psychosocial factors, emphasizing the significant mediating effects of digital health literacy and social support. Living arrangements emerged as a key moderator, with digital engagement having a stronger influence on cognitive function among older adults living alone, underscoring the need for tailored interventions in this vulnerable group. Importantly, the findings suggest that digital technology use can be an effective strategy to mitigate cognitive decline in later life, emphasizing that interventions need to go beyond access and foster capacities to obtain digital information resources and leverage social support.

Keywords

Digital Engagement, Cognitive Function, Digital health literacy, Social support, Living arrangements, Moderated mediation model



Introduction

Background

Cognitive function is a critical determinant of dementia, functional independence, quality of life, and healthcare burden [1]. With an increasingly aged population, cognitive impairment and dementia have become major health and social issues worldwide [2]. Research indicates that there are about 15.07 million patients with dementia in the population aged 60 and above in China, while the prevalence of mild cognitive impairment is 15.54%, and the number of patients is 38.77 million [3]. The disease burden of dementia and cognitive impairment is huge. The estimated total annual costs of dementia in China will reach 114.2 billion US dollars in 2030 [4]. Since there is currently no effective pharmaceutical treatment for dementia and MCI, it is important to identify modifiable intermediate risk factors that could prevent cognitive decline [5].

With rapid digitalization and the widespread integration of technology into daily life, digital technologies has emerged as a potential determinant of healthy aging. Nowadays, an increasing number of older adults engage with digital technologies and are becoming competent users [6]. In China, as of 2025, the number of internet users aged 60 and above has reached 161 million, accounting for nearly 14.4% of all internet users [7]. The environment shaped by technological developments provides new opportunities for older adults to address age-related cognitive decline. Engagement in cognitively challenging activities, such as learning new digital skills or knowledge, plays a protective role against age-related cognitive decline [8,9]. Meanwhile, access to communication technology and social media facilitates interpersonal interactions and enhances social support [10], which help maintain cognitive health in older adulthood.

Against this background, exploring the association between digital technology use and cognitive health in later life has become an important research focus. The existing evidence supports a positive association [11–13]. Empirical findings generally suggest that regular use of social media and online social networking is positively associated with better cognitive outcomes [14–16]. Longitudinal studies have shown that older adults who consistently use the internet exhibit slower rates of cognitive decline and a lower risk of dementia over time compared to non-users [17,18]. Meta-analyses of randomized controlled trials further support the effectiveness of digital interventions in improving specific cognitive domains [19,20]. Additionally, researchers have pointed out the underlying mechanisms through physical activity [21] and social support [22,23].

Although growing evidence links digital technology use with cognitive outcomes, two important research gaps remain. First, measurement has often been constrained by data availability, with many studies operationalizing technology use through binary indicators of internet use or crude frequency. Second, the interaction between family structure and digital technology use remains underexplored, even though family structure exerts a significant influence in the Chinese context. Addressing these gaps, guided by the technological reserve hypothesis, this study tested a moderated mediation model to examine whether digital engagement is associated with cognitive function through digital health literacy and social support, and whether these pathways are moderated by living arrangements.

Theoretical framework

Cognitive reserve is defined as “a property of the brain that allows for cognitive performance that is better than expected given the degree of life-course related brain changes and brain injury or disease” [24]. Building on this concept, the technological reserve hypothesis, developed by Benge and Scullin, focuses on how digital technology use can counteract cognitive decline and reduce disease burden [25–27]. Technological reserve is defined as “the development of a culture and environment of technology use in older adults that can buffer against the impact of cognitive decline on day-to-day activities” [25].

Further study developed the technological reserve concept and summarized three central pathways through which digital technology may prevent cognitive decline [26,28]. First, technology can generate cognitive complexity by engaging older adults in cognitively demanding activities that strengthen cognitive reserve [9,29]. By enabling access to diverse information sources (e.g., online health information), promoting mentally stimulating activities, and requiring continual learning and adaptation, digital technologies help sustain and challenge cognitive capacities [30]. Second, technology fosters social connection and engagement, which are well-established protective factors against cognitive decline [31]. Through platforms such as social media, messaging applications, and video calls, older adults can maintain social ties, reduce loneliness, and access emotional and instrumental support. Finally, technologies can function as cognitive prosthetics by directly compensating for lapses in memory and executive function, particularly those involved in completing activities of daily living. For example, smartphone applications can deliver reminders for medication adherence [32].

Digital engagement and cognitive function

Within the technological reserve framework, digital technology use as a modifiable lifestyle behavior

is a critical factor that can promote better cognitive outcomes than would be expected based on age, brain injury, or disease stage [28]. In this study, we adopted the term *digital engagement* to define digital technology use among older adults. Digital engagement among older adults refers to their use of contemporary digital technologies and devices to carry out routine and enjoyable everyday activities that support autonomy, independence, and social inclusion [33]. This concept emphasizes how older adults integrate information and communication technologies into daily activities and information-seeking behaviors rather than focusing on limitations [34].

Research has investigated the potential association between digital engagement and cognitive function among older adults. Although some studies suggest potential risks such as sleep disruption or social isolation [35–37], the prevailing evidence supports that digital engagement is positively linked to cognitive function [11–13]. Empirical findings generally suggest that regular use of digital technologies (such as social media and online social networking) is positively associated with better cognitive outcomes [14–16]. These benefits are often attributed to increased cognitive stimulation, enhanced social connectivity, and greater engagement in mentally active tasks afforded by digital technology [38,39]. Longitudinal studies further suggests that consistent internet use is associated with slower cognitive decline and a lower subsequent risk of dementia compared with non-use [17,18]. Meta-analyses of randomized controlled trials also support the effectiveness of digital interventions in improving specific cognitive domains [19,20]. Despite growing evidence, the mechanisms through which digital engagement benefits cognition remain insufficiently understood.

The mediating role of digital health literacy

Digital health literacy (DHL) is the ability to seek, understand, evaluate, and apply health information from digital sources to support health-related decision-making [40]. Within the framework of the technological reserve framework, DHL can strengthen cognition by engaging older adults in cognitively demanding processes such as evaluating online resources, learning new digital skills, and applying health information in daily life. These processes involve active learning, adaptive reasoning, and problem-solving, which are consistent with mechanisms that sustain cognitive reserve [28].

Moreover, empirical studies support this pathway. Higher DHL are associated with greater adoption of preventive health behaviors, better management of chronic conditions, improved adherence to treatment, and more informed health decisions [41–44]. Such behaviors not only enhance health outcomes but also contribute to maintaining and preserving cognitive function in later life. Thus,

DHL may mediate the association between digital engagement and cognitive function.

The mediating role of social support

Within the technological reserve framework, another plausible pathway operates through social connectivity. Social connectivity refers to the structural and functional aspects of individuals' social relationships, and in later life, is often reflected through social support received from their networks [45–47]. Social-emotional choice theory points out that social participation requires a certain cost investment, and members who engage in social participation are bound to consider cost-benefit issues [48]. For older adults, declining physical and cognitive abilities raise the cost of offline social participation, leading to a gradual reduction in face-to-face interactions [49]. Digital technologies offer alternative and more accessible avenues for maintaining social support [50].

Some empirical studies have shown that digital engagement is positively associated with increased social support in later life [51,50,52]. Social support, in turn, is a well-established protective factor for cognitive function: Older adults with stronger support networks tend to perform better cognitively and face a lower risk of cognitive decline or dementia [53–55]. Thus, social support may serve as a mediator linking digital engagement to cognitive outcomes.

The moderating role of living arrangements

Economic revolution and urbanization in China since the 1980s have profoundly reshaped family structures, particularly impacting older adults. This shift aligns with modernization theory, predicting smaller families and fewer older adults co-residing with children [56]. Consequently, more older adults live only with a spouse or alone [57]. Given the central role of family in Chinese culture, the study shifted to investigate the moderating role of living arrangements.

Living arrangements may shape both the opportunities and the need for engaging with digital technology [58]. Older adults living alone often rely on digital technologies to maintain social ties, bridge social gaps, and manage independent living [59,60]. In contrast, those in multi-generational households may experience “proxy internet use” (e.g., reliance on family members for online tasks), reducing direct engagement and the attendant cognitive stimulation [61]. Digital engagement may therefore be especially protective for those living alone.

Hypotheses

Guided by the technological reserve hypothesis, this study tested a moderated mediation model to examine whether digital engagement is associated with cognitive function through DHL and social

support, and whether these pathways are moderated by living arrangements (Figure 1). Based on the theoretical framework and prior empirical evidence, we propose the following hypotheses:

- Hypothesis 1: Higher digital engagement is correlated with greater cognitive function among older adults.
- Hypothesis 2: Higher digital engagement is associated with higher DHL among older adults.
- Hypothesis 3: Higher DHL is correlated with greater cognitive function among older adults.
- Hypothesis 4: DHL is a mediator between digital engagement and cognitive function among older adults.
- Hypothesis 5: Higher digital engagement is associated with greater social support among older adults.
- Hypothesis 6: Greater social support is correlated with greater cognitive function among older adults.
- Hypothesis 7: Social support is a mediator between digital engagement and cognitive function among older adults in China.
- Hypothesis 8: Living arrangements moderate the associations of digital engagement with cognitive function, DHL, and social support.

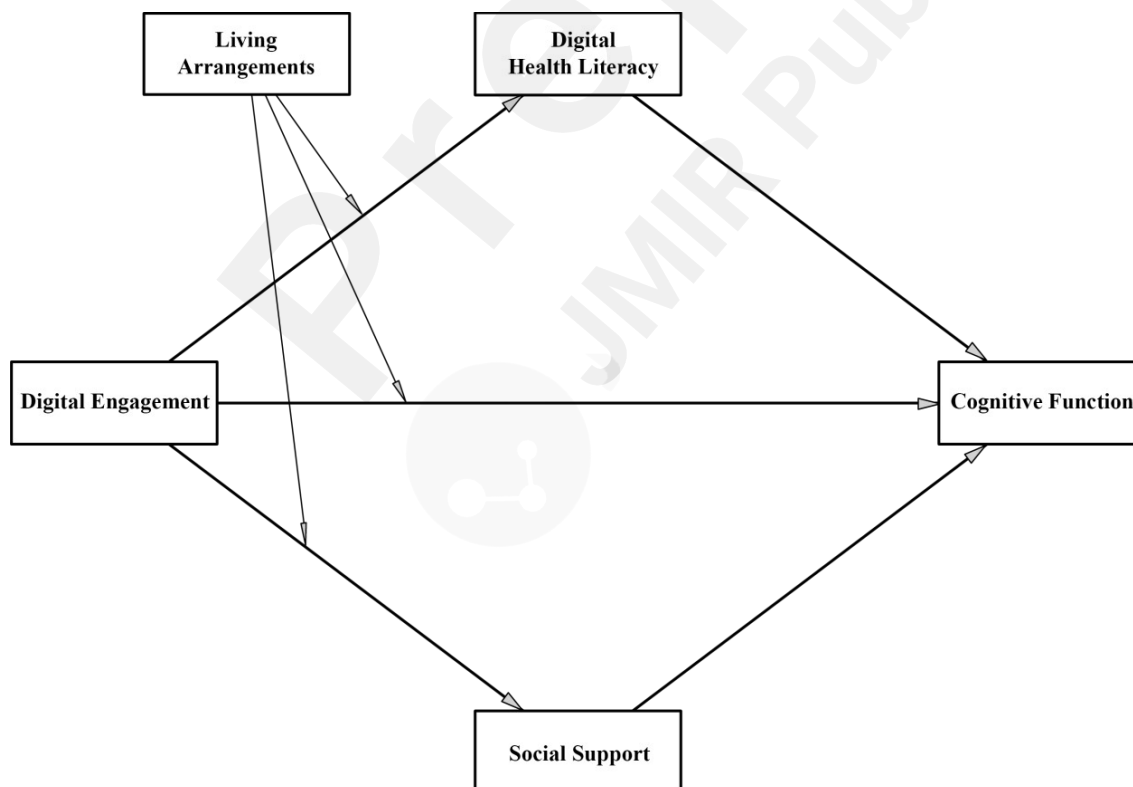


Figure 1. Moderated mediation model.

Methods

Study design

This study utilized data collected through a large-scale, cross-sectional survey conducted concurrently by five academic teams affiliated with four major universities in China. To ensure methodological uniformity, all participating sites adhered to a unified research protocol during the implementation phase.

A stratified, multistage sampling framework was employed to enhance the representativeness of the sample. To account for geographic and socioeconomic variation, 1-2 provinces were randomly chosen from each of China's eastern, central, and western regions. Within each selected province, 1-2 urban or county-level administrative units were further sampled based on their economic status. In the final stage, cluster sampling was used to select specific communities or villages, which served as the basic sampling units. All eligible older adults residing in the selected areas were invited to participate.

Sample size estimation followed the standard formula for proportion-based calculations:

$n = (u_{\alpha}^2 pq) / d^2$, where u_{α} represents the critical value for a 95% confidence level ($u_{\alpha}=1.96$), p is the estimated proportion of older Internet users based on the CNNIC's 51st Statistical Report [62], q is the complementary proportion ($q=1-p$), and d denotes the allowable error (1.2%). Based on these parameters, the minimum required sample size was calculated as 6,616. To account for possible non-responses and invalid questionnaires, a 20% oversampling rate was applied, resulting in a target sample of approximately 7940 individuals.

Data collection and quality control

Fieldwork was conducted from June to November 2024 by trained surveyors in collaboration with local village committees or community service offices. Face-to-face interviews were administered at participants' homes using standardized paper questionnaires. The interviews collected information on sociodemographic characteristics, digital technology use, digital literacy, cognitive function, and quality of life. All surveyors received centralized training to ensure consistent questionnaire administration and interpretation. Upon completion of each interview, field supervisors performed a thorough review of the questionnaires to check for completeness, internal consistency, and data accuracy before submission for entry.

Participants

Eligible participants were older adults who met the following inclusion criteria: (1) aged 55 years or older; (2) had resided in the survey location for at least six months; and (3) were able to communicate effectively with investigators. Exclusion criteria included: (1) individuals temporarily absent from their households during the survey period; (2) those diagnosed with terminal illnesses; and (3) those who declined to participate. Participants with incomplete responses, duplicate entries, or missing key variables were removed. Ultimately, valid data were collected from 8123 participants across six urban or county-level administrative units in Hubei, Shandong, Jiangsu, and Guangxi provinces, as illustrated in Figure 2.

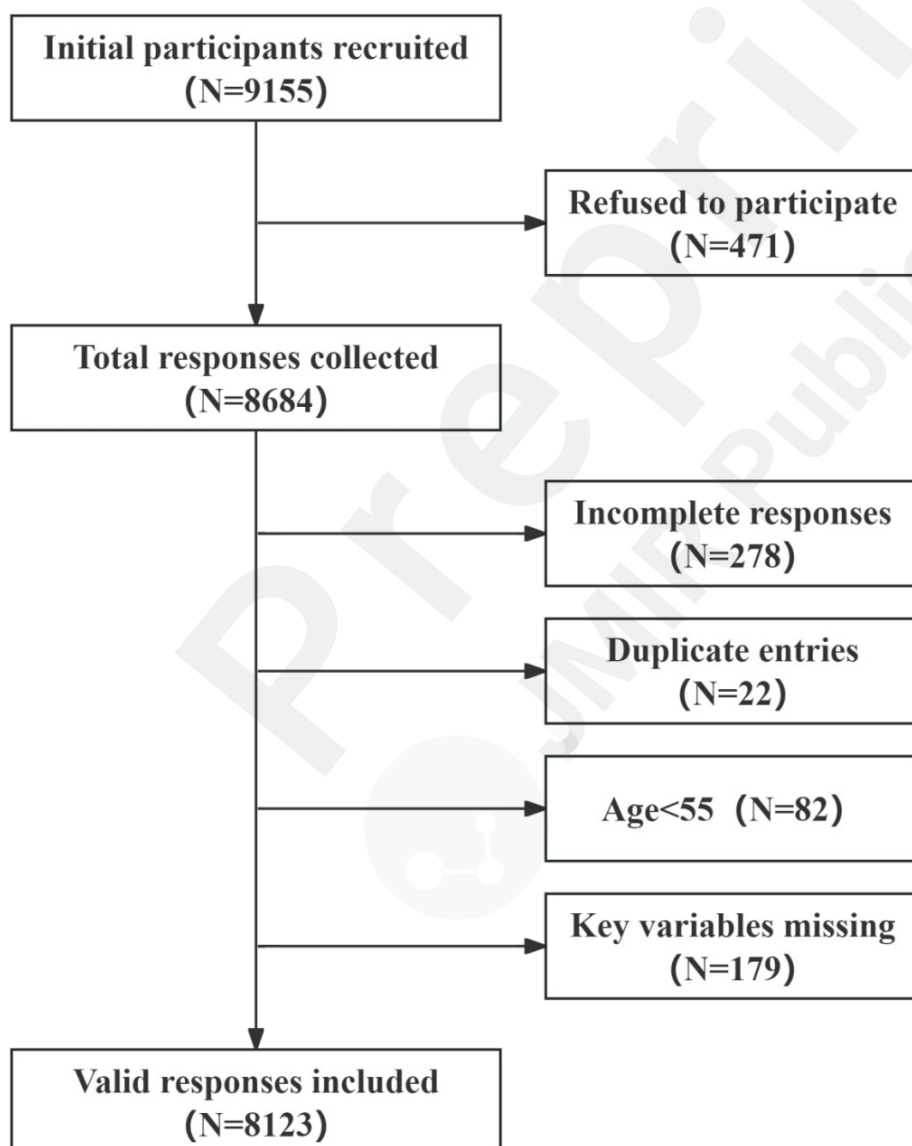


Figure 2. Flowchart of participant recruitment and data exclusion

Ethical Considerations

The study was reviewed and approved by the Medical Ethics Committee of Zhongda Hospital, Southeast University (Approval No. 2024ZDSYLL294-Y01). Written informed consent was obtained from all participants before they participated in the study.

Measurements

Cognitive function

Cognitive function was assessed using the Mini-Cog test. The Mini-Cog test is a rapid, valid, and reliable screening tool for cognitive impairment [63]. The Mini-Cog Test includes a three-word recall task (scored 0-3) and the clock drawing test (scored 0-2). The total score ranges from 0 to 5. In this study, the Mini-Cog total score was used as a continuous measure of cognitive function, with higher scores indicating better cognitive performance.

Digital engagement

Digital engagement was measured using a self-reported scale developed to capture older adults' frequency of participation in various digital activities. The scale included eight types of digital behaviors: (1) social communication (e.g., using WeChat voice/video calls), (2) experience sharing (e.g., posting on WeChat Moments, QQ Zone, or Weibo), (3) leisure and entertainment (e.g., playing online games, listening to music, or watching videos), (4) online transactions (e.g., transferring money, making payments, booking services, or trading stocks), (5) information seeking (e.g., searching for travel information or reading news), (6) online learning or training, (7) online civic participation (e.g., participating in online polls, petitions, or rights protection), and (8) political engagement (e.g., online voting or leaving messages on government websites). Participants rated the frequency of each activity on a 5-point Likert scale ranging from 1 (never) to 5 (always). Higher scores indicated higher digital engagement. The scale demonstrated good internal consistency in this sample (Cronbach's $\alpha = 0.876$).

Digital health literacy

DHL was assessed using the eHealth Literacy Scale (eHEALS), a widely validated instrument developed by Norman and Skinner to measure individuals' self-perceived skills in locating, evaluating, and applying electronic health information to health-related problems [40]. The eHEALS consists of eight items rated on a 5-point Likert scale (1 = strongly disagree to 5 = strongly agree), reflecting domains such as awareness of available online health resources, confidence in using the

internet for health decision-making, and the ability to discern high-quality digital health content. Given the linguistic and cultural differences between the original instrument and the target population of older adults in mainland China, we employed the simplified Chinese version (C-eHEALS) translated and validated by Ma and Wu [64]. The translation followed the WHO guidelines for cross-cultural adaptation, and its psychometric properties were confirmed in a rural Chinese population using both classical test theory and item response theory. In our sample, the C-eHEALS demonstrated excellent internal consistency, with a Cronbach's alpha coefficient of 0.986, indicating high reliability for use among Chinese older adults.

Social support

Social support was assessed using the 3-item short version of the Perceived Social Support Scale (PSSS-3), which was developed and validated by Wu and colleagues [65] specifically for use among the Chinese general population. This abbreviated scale was derived from the original 12-item Chinese version of the Multidimensional Scale of Perceived Social Support (MSPSS), originally adapted by Jiang [66] from the version developed by Zimet and colleagues [67]. The PSSS-3 includes one item from each of the three core dimensions—family support, friend support, and significant others—selected based on the highest factor loadings in a large-scale national sample. The Cronbach's α of PSSS-3 in this study was 0.868, demonstrating good internal consistency.

Living arrangements

Living arrangements were measured as a binary variable indicating whether the older adult lived alone, and were assessed using the following question: "What is your current living arrangements?" Those who reported living alone were coded as 1, and those who reported living with others were coded as 0.

Control Variables

The prior study indicates that demographic and health factors have close links with cognitive function and suggests that these factors should be included in pertinent research [68]. Gender, age, marital status, education, and number of chronic diseases were controlled as covariates by the aforementioned recommendations.

Statistical analysis

All analyses were performed using SPSS 27. Descriptive statistics summarized sample characteristics, with continuous variables reported as mean $\pm$ standard deviation and categorical

variables as frequencies and percentages. Pearson correlations examined associations among digital engagement, cognitive function, digital health literacy, social support, and living arrangements. Multicollinearity was assessed via the variance inflation factor (VIF), with $VIF > 5$ indicating collinearity. Mediation and moderated mediation analyses were conducted using model 4 and model 8 of the PROCESS macro for SPSS [69], based on 5000 bootstrap samples. Effects were considered significant if the 95% bias-corrected confidence interval did not include 0. All models controlled for age, gender, marital status, education, and number of chronic diseases. Continuous variables were standardized prior to analysis. Statistical tests were two-tailed with $\alpha = 0.05$.

Results

Demographic characteristics of the participants

The final sample consisted of 8123 older adults, with an average age of 71.03 years ($SD = 8.39$). Men accounted for 42.46% (3449/8123) of the participants. Most respondents were married (6338/8123, 78.03%), and 51.73% (4202/8123) of the participants had attained a middle school education or above. 75.28% (6115/8123) of the participants reported at least one chronic condition. Summary statistics for main variables, including digital engagement, digital health literacy, social support, living arrangements, and cognitive function, are presented in Table 1.

Table 1. Descriptive analyses of the study variables (N=8123).

Variables	Value
Gender, n (%)	
Male	3449 (42.46)
Female	4674 (57.54)
Age (years), mean (SD)	71.03 (8.39)
Marital status, n (%)	
Married	6338 (78.03)
Unmarried	1785 (21.97)
Education, n (%)	
Primary school or under	3921 (48.27)
Middle or high school	3462 (42.62)
College or above	740 (9.11)
Chronic diseases, n (%)	
0	2008 (24.72)
1	3477 (42.80)
≥ 2	2638 (32.48)
Digital engagement, mean (SD)	17.37 (8.03)
Digital health literacy, mean (SD)	20.18 (10.59)
Social support, mean (SD)	16.71 (3.22)
Living arrangements, n (%)	
Living alone	1166 (14.35)

Variables	Value
Living with others	6957 (85.65)
Cognitive function, mean (SD)	3.57 (1.49)

Preliminary correlation analysis

Table 2 presents the Pearson correlation coefficients among the main variables. Digital engagement was significantly and positively correlated with cognitive function ($r = 0.365$, $P < .001$), social support ($r = 0.081$, $P < .001$), and digital health literacy ($r = 0.575$, $P < .001$), but negatively associated with living arrangements ($r = -0.101$, $P < .001$). Cognitive function was also positively correlated with social support ($r = 0.131$, $P < .001$) and digital health literacy ($r = 0.347$, $P < .001$), and negatively correlated with living arrangements ($r = -0.069$, $P < .001$). Variance inflation factors indicated no multicollinearity among digital engagement (VIF = 1.732), digital health literacy (VIF = 1.666), social support (VIF = 1.027), living arrangements (VIF = 1.823), and cognitive function.

Table 2. Pearson correlation matrix of digital engagement, digital health literacy, social support, living arrangements and cognitive function.

Variables	Digital engagement	DHL ^a	Social support	Living arrangements	Cognitive function
Digital engagement					
r	1	0.575	0.081	-0.101	0.365
P value	— ^b	< .001	< .001	< .001	< .001
DHL					
r	0.575	1	0.127	-0.073	0.347
P value	< .001	—	< .001	< .001	< .001
Social support					
r	0.081	0.127	1	-0.045	0.131
P value	< .001	< .001	—	< .001	< .001
Living arrangements					
r	-0.101	-0.073	-0.045	1	-0.069
P value	< .001	< .001	< .001	—	< .001
Cognitive function					
r	0.365	0.347	0.131	-0.069	1
P value	< .001	< .001	< .001	< .001	—

^aDHL: digital health literacy.

^bNot applicable.

Mediation Analysis

We first used model 4 of the PROCESS macro for SPSS [69] to test Hypothesis 1 to 7. Table 3 and Figure 3 presents the results of the mediation analysis. As shown in model 3, the direct effect of digital engagement on cognitive function was significant ($\beta = 0.173$, $P < .001$), thus supporting

Hypothesis 1. Digital engagement also demonstrated a significant and positive association with DHL (Model 1, $\beta = 0.441$, $P < .001$), supporting Hypothesis 2. Additionally, DHL was significantly and positively related to cognitive function (Model 3, $\beta = 0.154$, $P < .001$), supporting Hypothesis 3. Furthermore, digital engagement was positively and significantly correlated with social support (Model 2, $\beta = 0.070$, $P < .001$), supporting Hypothesis 5. Social support, in turn, showed a significant and positive correlation with cognitive function (Model 3, $\beta = 0.088$, $P < .001$), Hypothesis 6.

Table 3. Mediation analysis of digital engagement on cognitive function.

Variables	Model 1 ^a (DHL ^b)		Model 2 ^c (Social support)		Model 3 ^d (Cognitive function)	
	β^e	<i>P</i> value	β	<i>P</i> value	β	<i>P</i> value
Explanatory variable						
Digital engagement	0.441	<.001	0.070	<.001	0.173	<.001
Mediator variables						
DHL	— ^f	—	—	—	0.154	<.001
Social support	—	—	—	—	0.088	<.001
Control variables						
Gender	-0.001	.939	0.122	<.001	-0.039	.059
Age	-0.010	.283	0.021	.086	-0.090	<.001
Marital status	0.040	.073	0.158	<.001	0.136	<.001
Education	0.403	<.001	0.014	.481	0.193	<.001
Chronic diseases	-0.113	<.001	-0.092	<.001	0.037	.008
Constant	-0.555	<.001	-0.239	<.001	-0.396	<.001

^a $F_{6, 8123} = 880.054$; $R^2 = 0.395$.

^bDHL: digital health literacy.

^c $F_{6, 8123} = 24.635$; $R^2 = 0.018$.

^d $F_{8, 8123} = 240.573$; $R^2 = 0.192$.

^e β : standardized regression coefficient.

^fnot applicable.

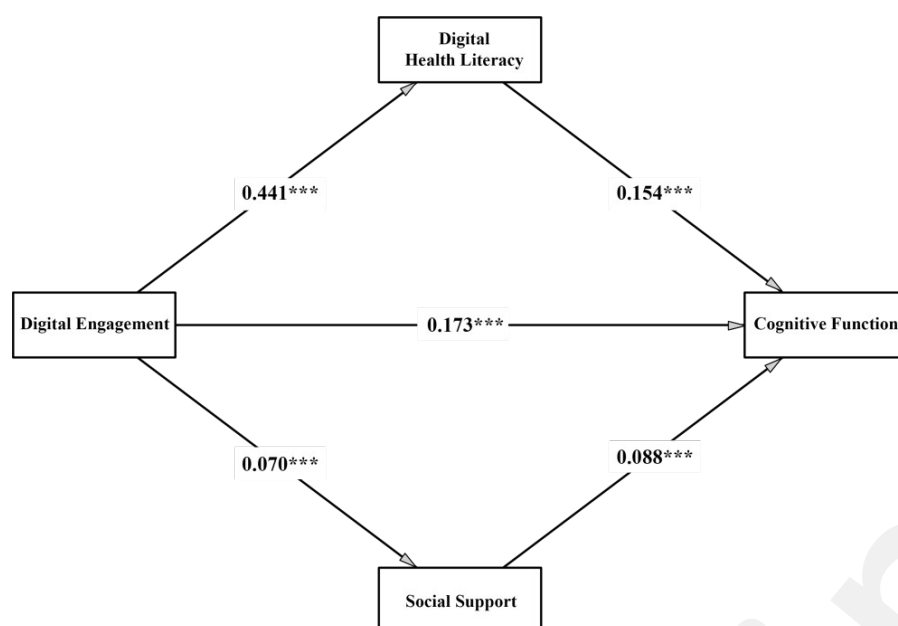


Figure 3. Mediation model of the association between digital engagement and cognitive function through digital health literacy and social support. *** $p < .001$.

These findings suggest that DHL and social support play a partial mediating role in the relationship between digital engagement and cognitive function, with indirect effects of 0.068 (95% CI 0.057 to 0.079) and 0.006 (95% CI 0.004 to 0.009), respectively, supporting Hypothesis 4 and 7. Combining two mediation effects, the total indirect effect was 0.074 (95% CI 0.062 to 0.086). The bootstrap test results for indirect effects are reported in Table 4.

Table 4. Bootstrap test results for indirect effects.

Indirect effects path	Effects	SE	LLCI	ULCI	Proportion of effects (%)
Total indirect effect	0.074	0.006	0.062	0.086	100
DE ^a → DHL ^b → CF ^c	0.068	0.006	0.057	0.079	91.89
DE → SS ^d → CF	0.006	0.001	0.004	0.009	8.11

^aDE: digital engagement.

^bDHL: digital health literacy.

^cCF: cognitive function.

^dSS: social support.

Moderated Mediation Analysis

To examine the moderated mediation effects involving living arrangements, we employed Model 8 of the PROCESS macro for SPSS [69], utilizing 5000 bootstrap resamples and a 95% bias-corrected confidence interval. The results are reported in Table 5. The analysis revealed a significant and positive interaction effect between digital engagement and living arrangements on cognitive function (Model 6, $\beta = 0.110$, $P < .001$), suggesting a moderating role of living arrangements. As illustrated in

Figure 4, the beneficial association between digital engagement and cognitive performance was stronger among older adults who lived alone, relative to those who lived with others.

Table 5. Moderated mediation analysis of digital engagement on cognitive function.

Variables	Model 4 ^a (DHL ^b)		Model 5 ^c (Social support)		Model 6 ^d (Cognitive function)	
	β^e	<i>P</i> value	β	<i>P</i> value	β	<i>P</i> value
Explanatory variable						
Digital engagement	0.432	<.001	0.050	<.001	0.159	<.001
Mediator variables						
DHL	— ^f	—	—	—	0.152	<.001
Social support	—	—	—	—	0.086	<.001
Moderating variables						
Living arrangements	0.060	.074	0.054	.212	0.156	<.001
DE×LA ^g	0.062	.014	0.153	<.001	0.110	<.001
Control variables						
Gender	-0.002	.927	0.121	<.001	-0.039	.061
Age	-0.010	.287	0.021	.084	-0.090	<.001
Marital status	0.067	.021	0.171	<.001	0.190	<.001
Education	0.401	<.001	0.009	.648	0.214	<.001
Chronic diseases	-0.113	<.001	-0.091	<.001	0.037	.008
Constant	-0.580	<.001	-0.242	<.001	-0.469	<.001

^a $F_{8, 8123} = 661.531$; $R^2 = 0.395$.

^bDHL: digital health literacy.

^c $F_{8, 8123} = 21.382$; $R^2 = 0.021$.

^d $F_{10, 8123} = 195.630$; $R^2 = 0.195$.

^e β : standardized regression coefficient.

^fnot applicable.

^gDE×LA: the interaction term between digital engagement and living arrangements.

In addition to the interaction effect on the direct path, the results also revealed significant moderating effects of living arrangements on the first stages of both mediation pathways. Specifically, the interaction term between digital engagement and living arrangements significantly predicted DHL (Model 4, $\beta = 0.062$, $P = .014$) and social support (Model 5, $\beta = 0.153$, $P < .001$). As illustrated in Figure 5 and 6, the beneficial association of digital engagement with both DHL and social support was stronger among older adults who lived alone, relative to those who lived with others. These findings indicate that living arrangements moderate the associations of digital engagement with cognitive function, DHL, and social support, supporting Hypothesis 8.

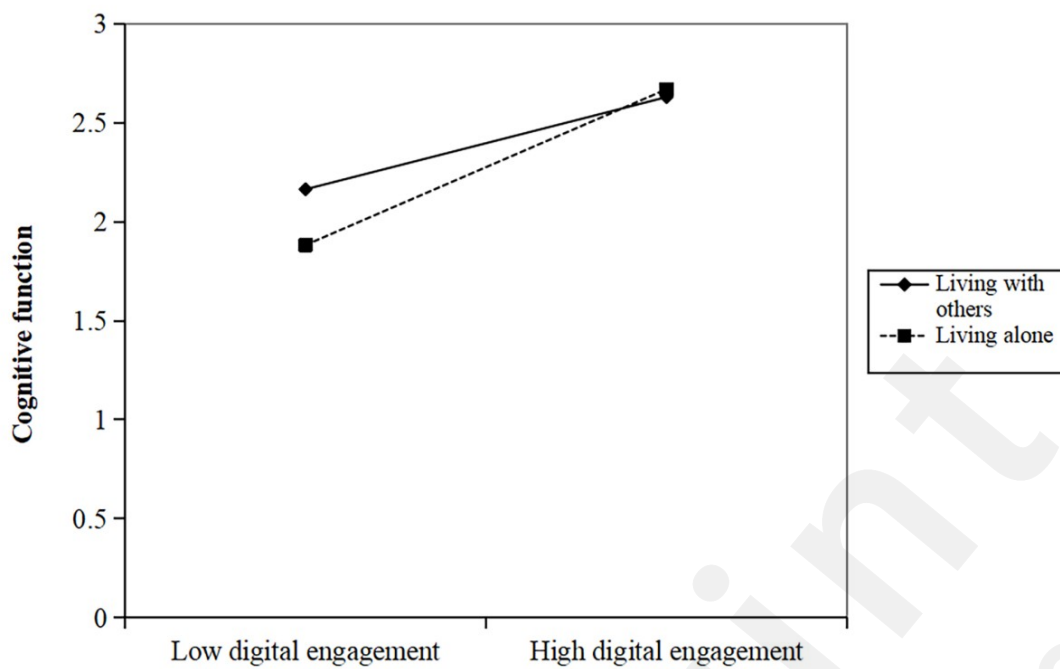


Figure 4. The interactive effect of digital engagement and living arrangements on cognitive function.

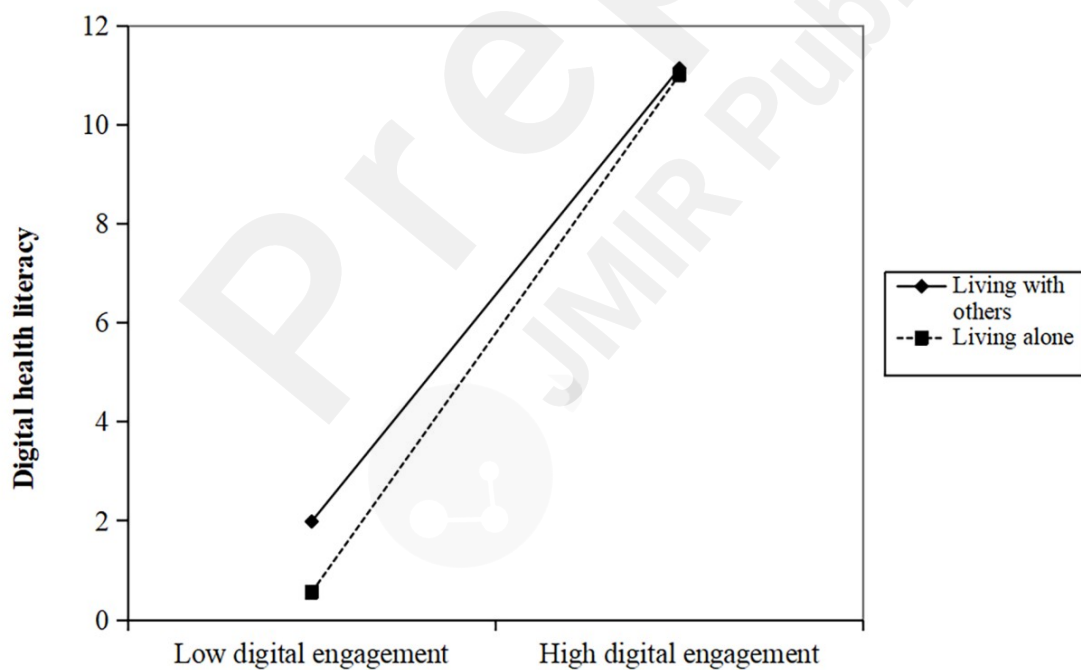


Figure 5. The interactive effect of digital engagement and living arrangements on digital health literacy.

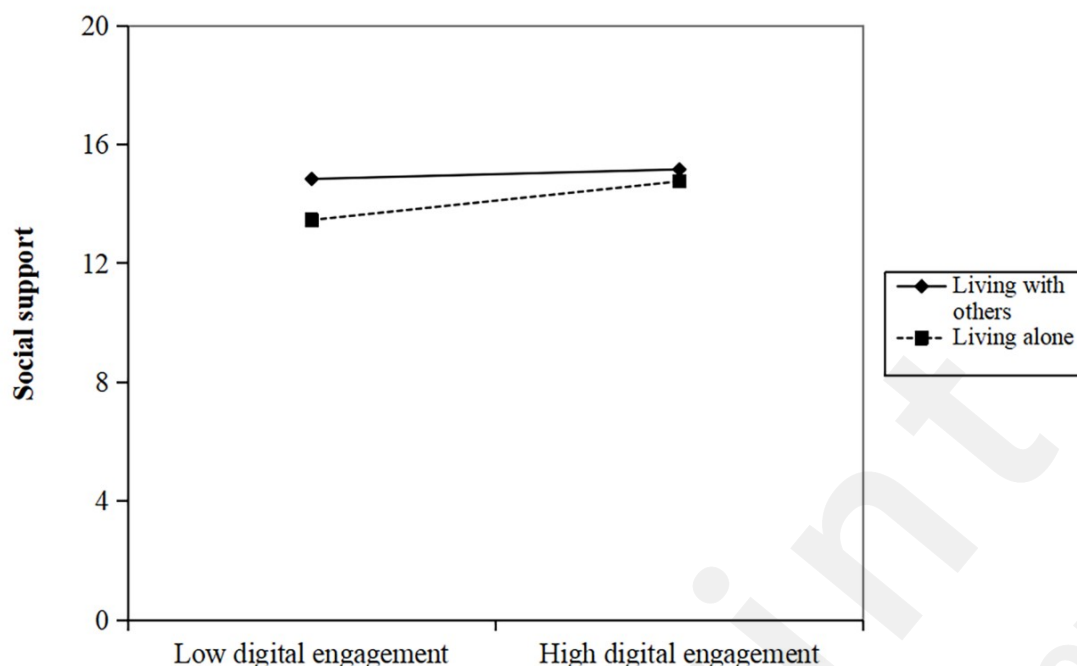


Figure 6. The interactive effect of digital engagement and living arrangements on social support.

Table 6 reports the conditional indirect effects of digital engagement on cognitive function by each path. For the DHL mediator, the indirect effect of digital engagement on cognitive function was 0.066 (95% CI 0.055 to 0.077) among participants living with others and 0.075 (95% CI 0.062 to 0.089) among those living alone. The corresponding index of moderated mediation was 0.009 (95% CI 0.003 to 0.017), indicating a significantly stronger indirect effect by digital health literacy for participants living alone. Similarly, for the social support mediator, the indirect effect was 0.004 (95% CI 0.002 to 0.007) for those living with others and 0.017 (95% CI 0.011 to 0.025) for those living alone. The index of moderated mediation for the social support pathway was 0.013 (95% CI 0.007 to 0.020). In all cases, the 95% confidence intervals excluded zero, indicating that both indirect effects were significantly stronger among older adults living alone.

Table 6. Conditional indirect effects of digital engagement on cognitive function through digital health literacy and social support.

Conditional indirect effects path	Effects	SE	LLCI	ULCI
DE ^a → DHL ^b → CF ^c (Living with others)	0.066	0.006	0.055	0.077
DE → DHL → CF (Living alone)	0.075	0.007	0.062	0.089
Index of the moderated mediation	0.009	0.004	0.003	0.017

DE → SS ^d → CF (Living with others)	0.004	0.001	0.002	0.007
DE → SS → CF (Living alone)	0.017	0.004	0.011	0.025
Index of the moderated mediation	0.013	0.003	0.007	0.020

^aDE: digital engagement.

^bDHL: digital health literacy.

^cCF: cognitive function.

^dSS: social support.

Discussion

Principal Findings

Guided by the technological reserve hypothesis and using a large, community-based sample of older adults in China, this study investigated the mechanisms underlying the association between digital engagement and cognitive function among older Chinese adults. We found that higher digital engagement was associated with better cognitive performance. Digital health literacy (DHL) and social support partially mediated this association, and living arrangements moderated both the direct and indirect pathways, with stronger benefits among older adults living alone. These findings extend prior work on technology use and cognition in later life and broaden the application of the technological reserve hypothesis in the Chinese context.

The Association Between digital engagement and cognitive function

Consistent with the technological reserve hypothesis, digital engagement was significantly and positively associated with cognitive function. This supports the view that digital technology use is a modifiable behavioral factor that can promote better cognitive outcomes [28]. It also aligns with prior work linking internet or computer use to cognition [70–75] and with recent studies in China demonstrating that internet use and digital activities enhance cognitive function [21,17]. By adopting the construct of digital engagement rather than a simple use-versus-nonuse dichotomy, our study advances the field by situating technology use within the everyday life context of older adults, emphasizing how they integrate information and communication technologies into their ongoing activities, social interaction, and information seeking [34]. This finding implies that encouraging sustained and meaningful digital engagement is a promising strategy for public health and aging policies aiming to strengthen cognitive function among older adults.

The mediating role of digital health literacy and social support

Consistent with the cognitive-stimulation pathway posited by the technological reserve hypothesis, higher digital engagement was associated with higher DHL, which in turn related to better cognitive performance [26,28]. Specifically, engaging with digital technology improves DHL because digital skills are among the core skills of DHL [76,77]. In turn, higher DHL denotes a stronger capacity to seek, understand, appraise, and apply health information [78]. These processes involve engaging with cognitively complex information [28], helping older adults build cognitive reserve. This finding advances the eHealth Literacy Model, which posits that DHL is underpinned by cognition [79], and indicates that DHL also serves as a tool that shapes cognition through ongoing, cognitively complex digital activities. Accordingly, interventions should combine user-friendly interfaces with structured, progressive training in cognitively complex digital tasks, ensuring that everyday digital engagement serves as sustained cognitive stimulation.

Social support mediated the association between digital engagement and cognition, consistent with the social-connectivity pathway [26,28]. This finding aligns with previous research showing that digital engagement has the potential to enhance cognitive function among older individuals by addressing feelings of loneliness and improving the social support they receive from relatives and friends [22]. Specifically, digital engagement enables cheap and easy communication between older adults in distant communities, increasing social connections, overcoming social and spatial barriers, and providing a convenient way to stay in touch with families, friends, and the outside world [51]. In turn, better social support is associated with better cognitive outcomes in older adults [54,80–83]. This finding underscores that interventions should help older adults form and maintain digital social ties so that online interactions translate into perceived social support and, ultimately, better cognitive outcomes.

The moderating role of living arrangements

Our study further revealed that living arrangements played a significant moderating role in the associations of digital engagement with cognitive function, digital health literacy, and social support. Compared with older adults who live with others, those living alone experienced a significantly stronger positive effect of digital technology engagement on cognitive function, consistent with the previous studies [84,11]. This moderating effect was significantly present in both mediating pathways: older adults living alone gained greater benefits in terms of digital health literacy and social support from digital engagement than those living with others. Specifically, older adults living alone, due to a lack of effective offline social interactions, are more reliant on virtual social networks

facilitated by digital technologies [49]. This reliance partially compensates for the reduced social support associated with solitary living, thereby mitigating its negative impact on cognitive function [59]. Additionally, older adults who live alone are less likely to engage in proxy internet use [61], and thus rely more on themselves to use digital devices (e.g., searching for health information online). Furthermore, since older adults living alone are less often burdened with caregiving responsibilities for grandchildren, they have more freedom and time to engage with digital technologies [11]. Our findings suggest that digital engagement serves as a more efficacious strategy for mitigating cognitive decline among older adults living alone compared to those living with others. Given the stronger benefits among older adults living alone, interventions should prioritize this vulnerable group.

Limitations and Future Research

Despite these contributions, several limitations should be acknowledged. First, the cross-sectional design precludes causal inferences. Although our models adjusted for a set of covariates, endogeneity, reverse causation, and unmeasured confounding cannot be fully ruled out. Thus, our results only show associations, not causality. Future studies should utilize longitudinal designs with extended follow-up periods to elucidate temporal dynamics and disentangle potential reverse causation. Second, reliance on self-reported measures introduces the risk of recall bias, especially among participants with cognitive impairments, despite our use of validated instruments to attenuate this issue. Finally, due to data constraints, living arrangements were operationalized as solitary versus non-solitary living, precluding differentiation among various household compositions (e.g., living with a spouse, children, or extended family). Given the important role of family structures in the well-being of older adults in China, future research should refine classifications of living arrangements to better explore their moderating effects.

Conclusions

This study contributes to the growing literature on technology and aging by demonstrating how digital engagement can promote later-life cognitive health within the framework of the technological reserve hypothesis. Rather than focusing only on access, our findings emphasize the importance of understanding the mechanisms and conditions through which digital engagement supports cognitive health. Future research should continue to refine these pathways and inform the design of inclusive, context-specific interventions that harness digital technologies to promote healthy cognitive aging in diverse populations.

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Conflicts of Interest

None declared.

Data Availability

As this study is a part of a major ongoing research project funded by the National Social Science Fund of China (NSSFC), relevant data are highly confidential and not publicly available.

Authors' Contributions

GRT designed this study. YQD wrote the initial draft. JQC supervised the writing of the manuscript. QN contributed to the design of the methodology, data collection, data analysis. SXJ and LXW revised and reviewed the manuscript.

Abbreviations

CF—cognitive function

DHL—digital health literacy

DE—digital engagement

SS—social support

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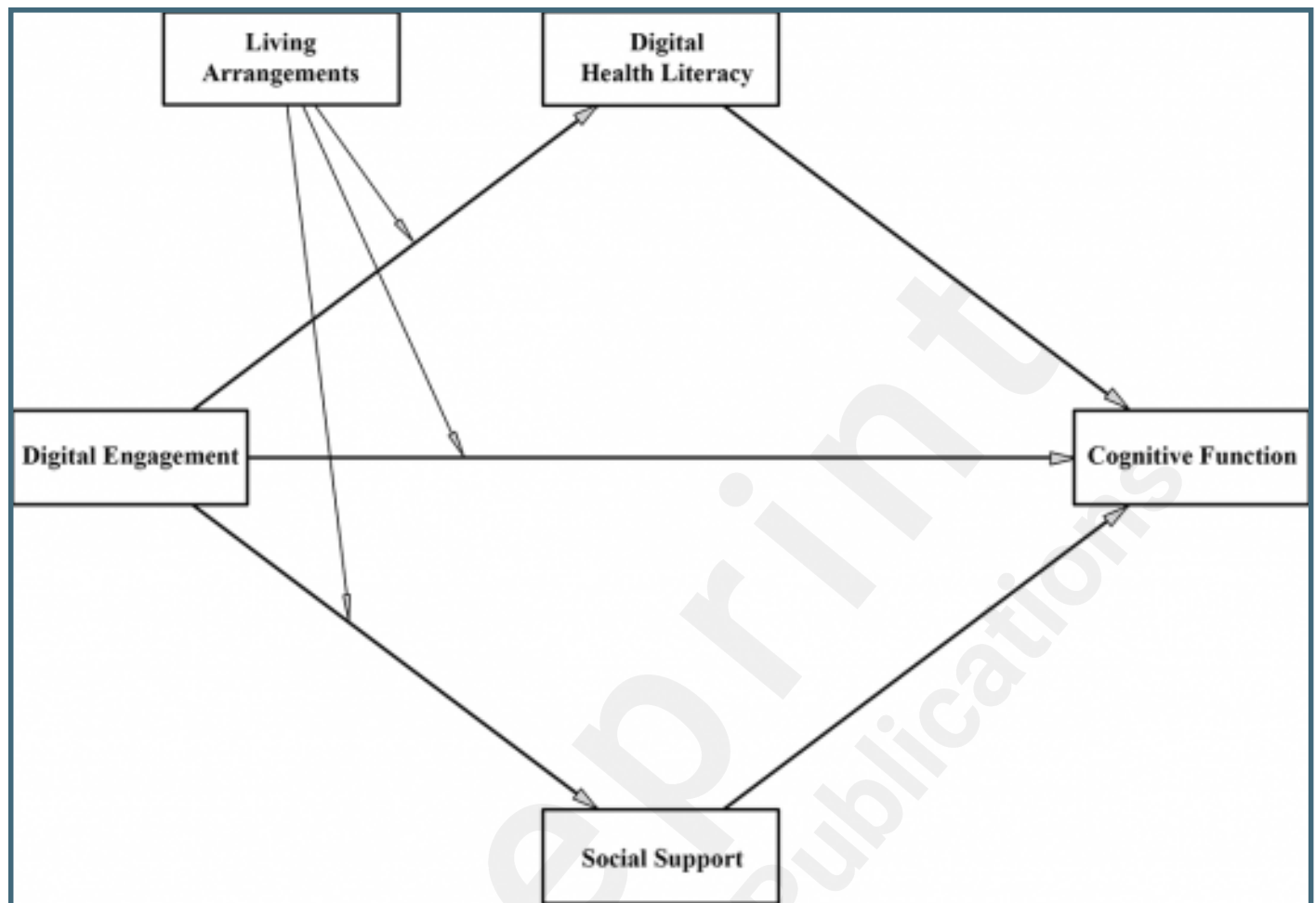
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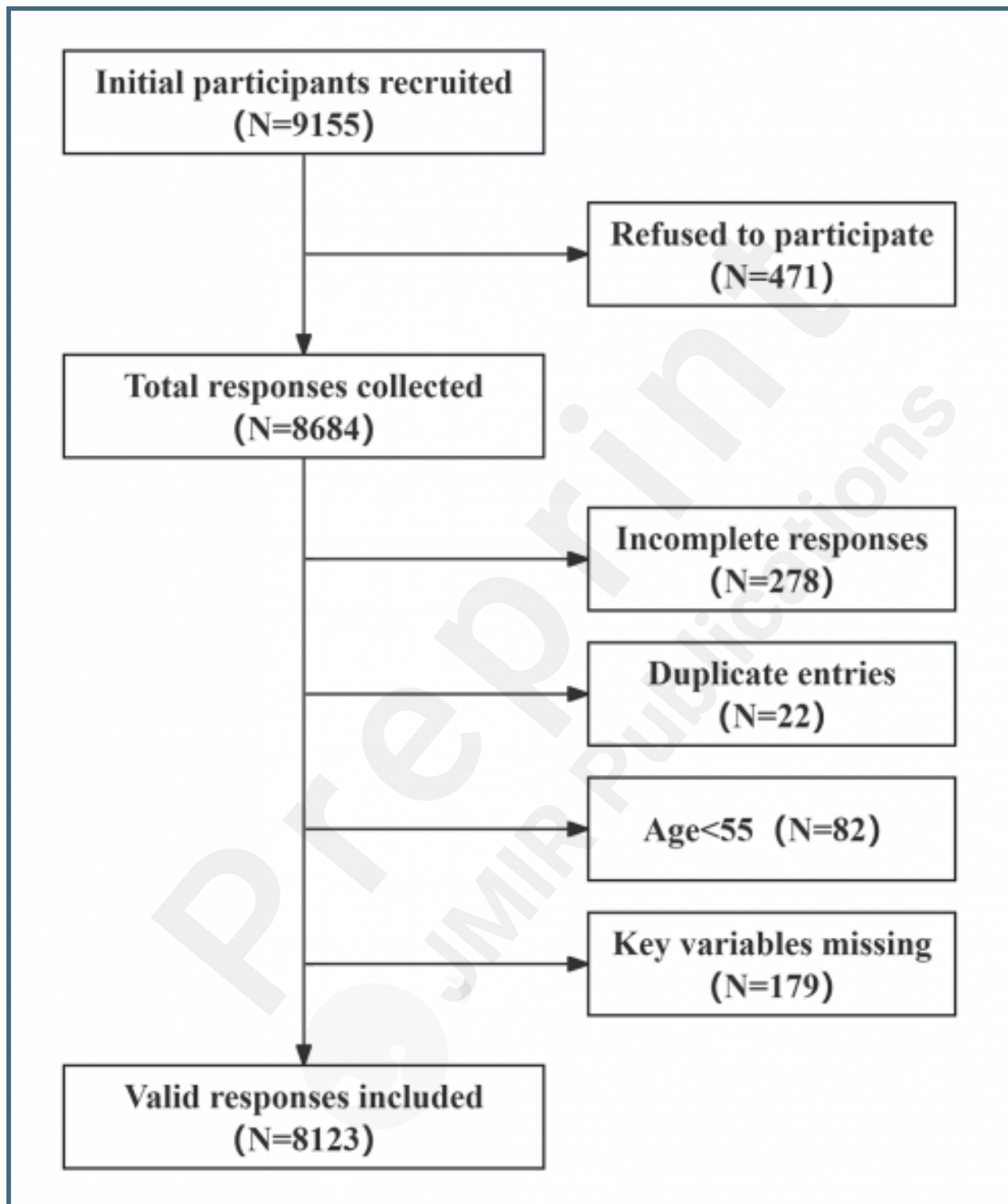
Supplementary Files

Figures

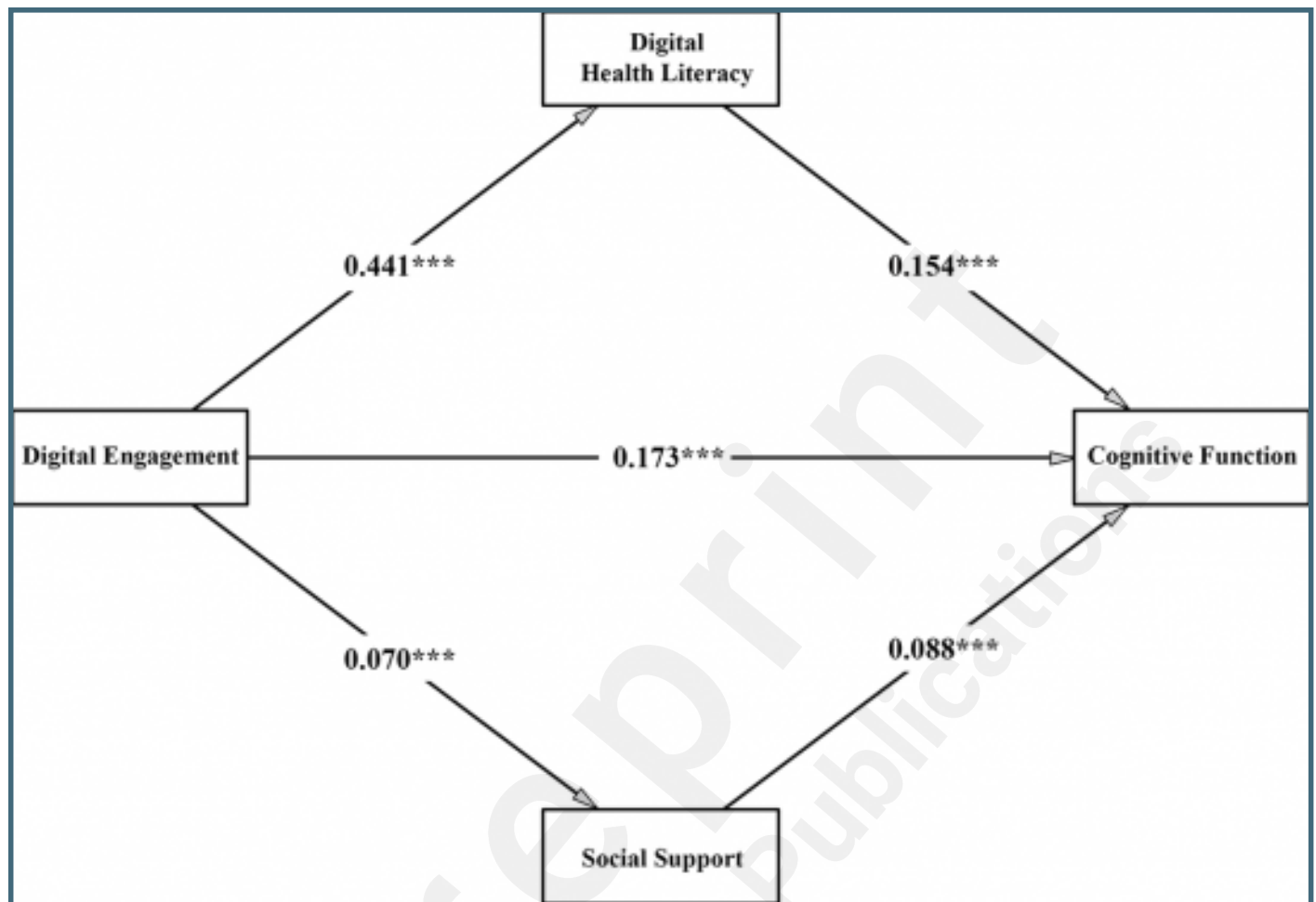
Moderated mediation model.



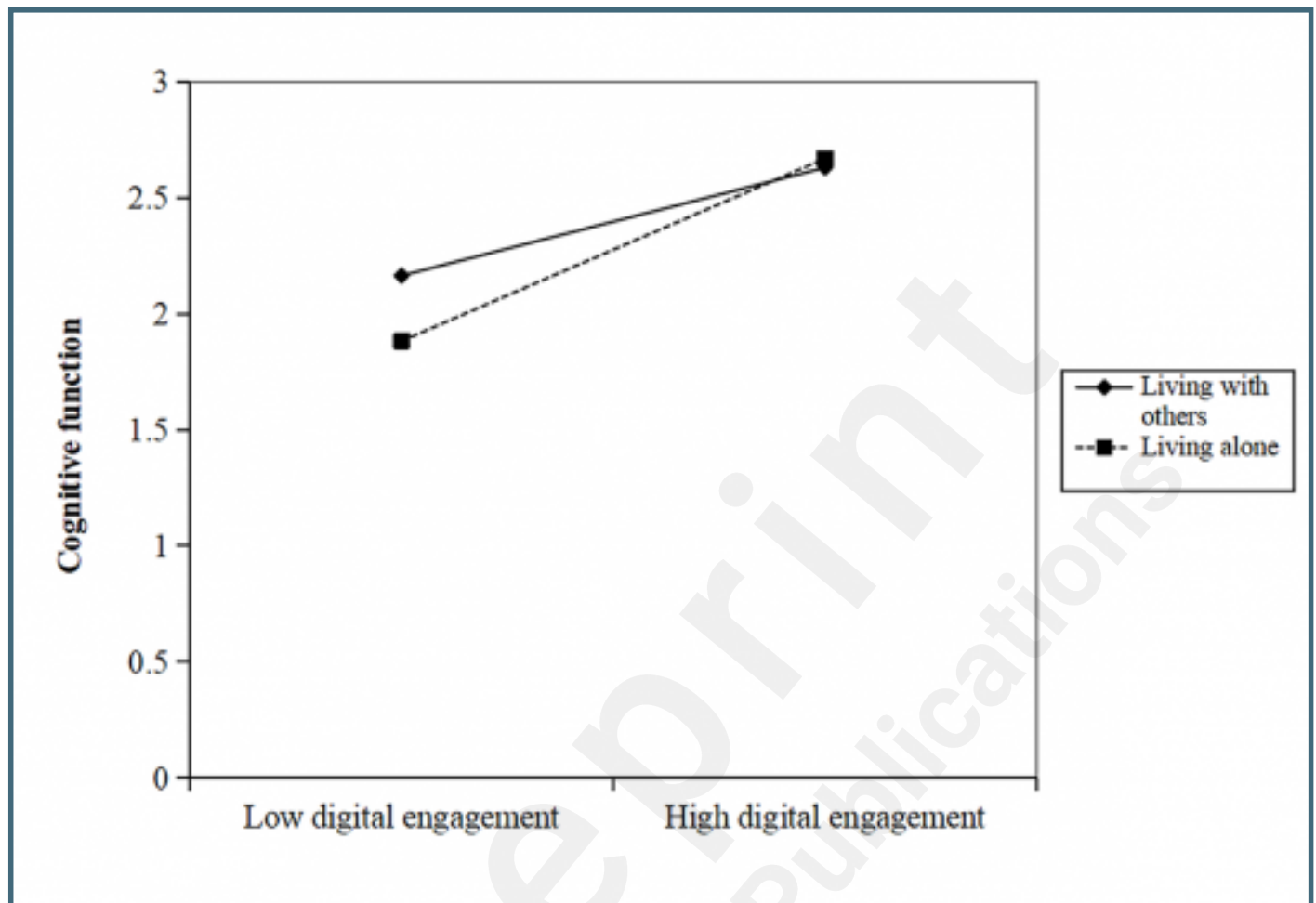
Flowchart of participant recruitment and data exclusion.



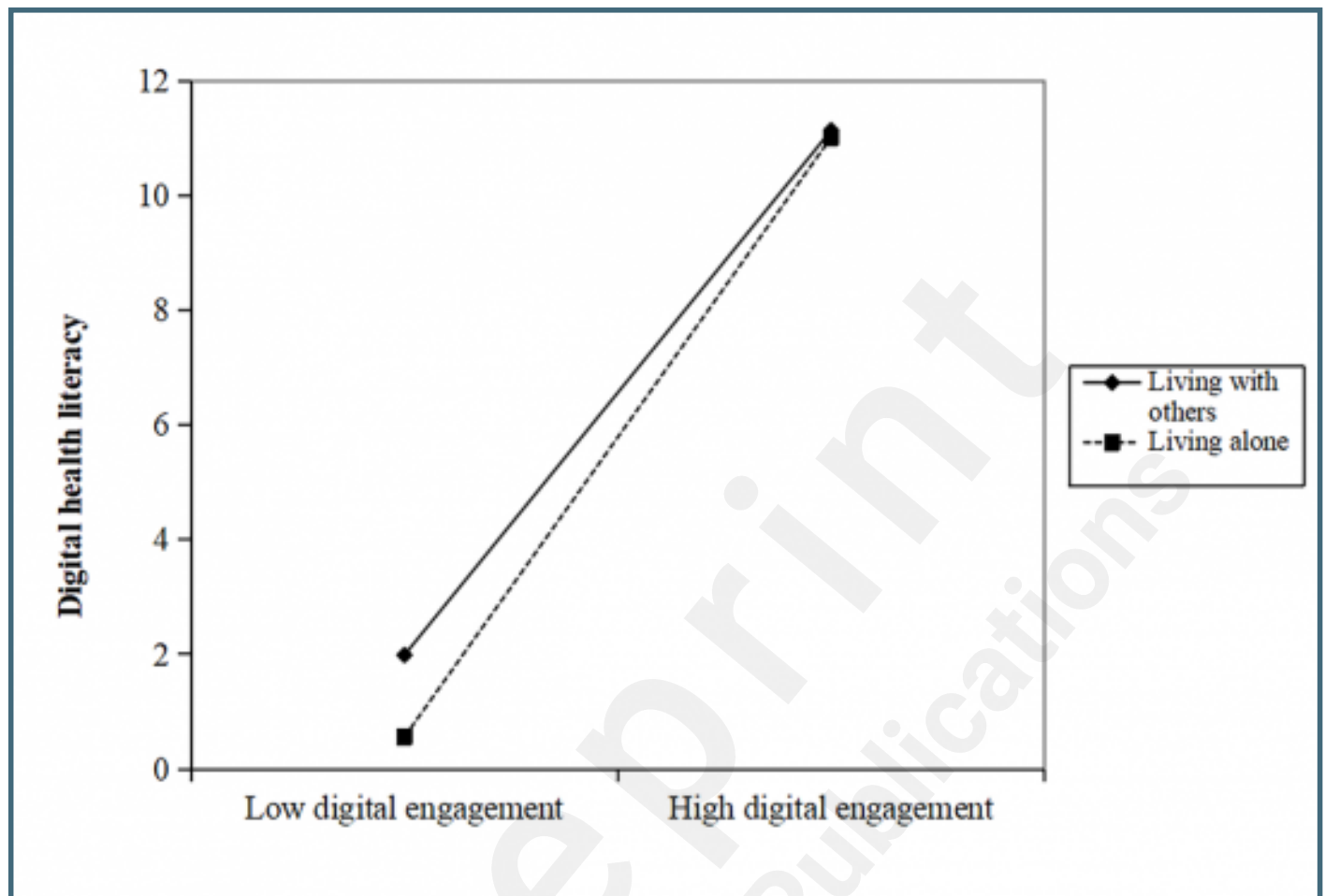
Mediation model of the association between digital engagement and cognitive function through digital health literacy and social support. *** $p < .001$.



The interactive effect of digital engagement and living arrangements on cognitive function.



The interactive effect of digital engagement and living arrangements on digital health literacy.



The interactive effect of digital engagement and living arrangements on social support.

