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The Bidirectional Association Between Physical and Cognitive Function Among Chinese Older Adults: A Mediation Analysis

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Abstract

This study investigated the bidirectional association between physical and cognitive function in later life and examined the mechanisms underlying the interrelationship. We employed cross-lagged panel models to analyze a sample of 4232 unique participants aged 65 years and older from three waves of the Chinese Longitudinal Healthy Longevity Survey. Physical activity and social participation were tested as potential mediators between physical and cognitive function. Our findings revealed a reciprocal relationship between physical and cognitive function and a reciprocal relationship between physical and cognitive decline. Moreover, physical activity was confirmed to mediate the bidirectional association between physical and cognitive function, whereas social participation did not seem to be a mediator. A vicious cycle linking physical and cognitive decline may exist in Chinese older adults. However, leading a physically active lifestyle could be an effective intervention to slow physical and cognitive aging, thereby toning down the vicious cycle.

Keywords

physical function, cognitive function, older adults, mediation analysis, cross-lagged panel model

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Introduction

Background and Aims

As an essential determinant of independent living and quality life in late adulthood, the maintenance of high levels of physical and cognitive functions is a hallmark of successful aging (Rowe & Kahn, 1997). Physical function is theoretically composed of four subdomains, which are mobility related to the lower extremities, dexterity related to the upper extremities, axial or central related to neck and back functions, and complex activities that involve more than one aforementioned subdomain (Dias, 2014). Cognitive function refers to mental processes involved in the acquisition of knowledge, manipulation of information, and reasoning (Kiely, 2014). Age-related declines in physical and cognitive functions are closely associated with elevated risks of disability (Dodge et al., 2005; Guralnik et al., 1995) and mortality (Kelman et al., 1994; Studenski et al., 2011), and therefore, are recognized as major health threats to older adults. Although a large body of literature has shown that physical and cognitive functions in older adulthood were influenced by a complex set of biological, behavioral, and lifestyle factors (Goins & Pilkerton, 2010), researchers have paid less attention to the interdependence between physical and cognitive function. Understanding the interdependence may shed light on the aging process in which declines in different functional domains reinforce each other and thereby lead to disability and death (Krall et al., 2014). Moreover, ascertaining the mechanisms underlying the interdependence between physical and cognitive function may contribute to developing effective health interventions to delay the onset of functional declines, but little research has been done in this area.

While a growing body of research has examined the interdependence between physical and cognitive function in later life in developed countries, especially in the United States, researchers have paid much less attention to the same topic in developing countries, thereby missing an important piece of the puzzle in understanding the relationship between the two functional domains in different geographic and social contexts. To date, population aging has become a prevalent phenomenon in many developing countries, and 80% of the two billion older people on this planet will be in the developing world by 2050 (Shetty, 2012). Thus, it is increasingly important to investigate older adults' health and its determinants in developing countries, such as China. As a populous country and an emerging economy, China is faced with a series of challenges posed by population aging, one of which is the current older adults' poorer physical and cognitive functions than those of earlier birth cohorts, in spite of the former's lower mortality risk (Zeng et al., 2017). Nonetheless, we have yet to see any research examining the temporal relationship between physical and cognitive function among Chinese older adults and the relevant mechanisms.

To fill the gaps discussed above and to develop a better understanding of the aging process connected with declines in physical and cognitive functions, the present study aims to assess the bidirectional relationship between physical and cognitive function in Chinese older adults and estimate the mediating effects of physical activity and social participation in the bidirectional relationship. To the best of our knowledge, this is the first study examining the interrelationship between physical and cognitive function and explores the mediators in a non-Western context with nationally representative data. Moreover, our mediation analyses drawing on longitudinal data may provide insights into the development of health interventions that seek to promote health and independent living in later life.

In the following sections, we first discuss the literature on the interdependence between physical and cognitive function and its limitations. We then develop arguments about the mechanisms that may mediate the reciprocal relationship. Next, we introduce the data and the empirical strategy, which are followed by the results and their implications.

The Interrelationship Between Physical and Cognitive Function

According to the systematic review by Clouston et al. (2013), previous studies have mostly examined the longitudinal association between physical and cognitive function in only one direction, that is, the association of baseline physical performance with subsequent cognition (or subsequent cognitive decline; e.g., Boyle et al., 2009; Inzitari et al., 2007; Gatz et al., 2010). Researchers have recently investigated the temporal relationship between physical and cognitive function in late adulthood in both directions, but such studies generated conflicting findings. Some studies suggested a unidirectional relationship between physical and cognitive function (Atkinson et al., 2010; Best et al., 2016; Mielke et al., 2013; Taekema et al., 2012), while others reported a reciprocal process (Gale et al., 2014; Krall et al., 2014; Stijntjes et al., 2017; Tian et al., 2016). For instance, two studies, conducted in the United States and the Netherlands, respectively, indicated that baseline cognitive function was associated with the decline in grip strength, whereas baseline grip strength was not associated with cognitive decline (Atkinson et al., 2010; Taekema et al., 2012). However, this conclusion is inconsistent with the study on older Mexican Americans by Alfaro-Acha et al. (2006), which suggested that lower baseline grip strength was associated with lower cognitive function over time. Moreover, (Stijntjes et al. (2017)) found a reciprocal relationship between cognition and grip strength in the oldest old (i.e., 85–90 years old) in the Netherlands. In addition to contextual and methodological factors, these mixed findings may be attributed to the differences in some survey features, such as the characteristics of participants, the duration of follow-up, and the types of measures of physical and cognitive function (Tian et al., 2016).

Some previous studies have also exposed methodological weaknesses, the first of which is the inability to clearly model the temporal relationship between physical and cognitive function. For example, some studies employed latent growth curve models (LGCMs) to depict the relationship (Bishop et al., 2016; Deary et al., 2011), which could be overly simplistic for examining the interplay between physical and cognitive function over time (Barker et al., 2014). Specifically, the LGCM only provides information on the contemporaneous association between initial physical function and initial cognitive function, the contemporaneous association between the overall rate of physical decline and the overall rate of cognitive decline, and the association between initial physical or cognitive function and the overall rate of change in the alternate functional domain (Bishop et al., 2016; Deary et al., 2011). The LGCM can thus assess neither the interplay between physical and cognitive function in a temporal order nor the interplay between physical and cognitive change in a temporal order.

Moreover, while there have been some studies on the interrelationship between physical and cognitive function, much fewer studies have investigated the predictive effects of the decline in one function (i.e., physical or cognitive function) on the subsequent decline in the other. Only one previous study has directly examined whether physical or cognitive change can predict a subsequent change in the alternate functional domain by taking into account the longitudinal within-person comparisons in terms of each function (Best et al., 2016). Additional research is needed to examine the interplay between physical and cognitive change, because if a positive reciprocal relationship does exist, the decline in one functional domain can be viewed as an early warning of a subsequent decline in the other, which facilitates early health interventions in functional impairments once clinicians identify a decline in either function.

Potential Mediators Between Physical and Cognitive Function

As mentioned earlier, despite a growing body of research focusing on the relationship between physical and cognitive function in late adulthood, little is known about the mechanisms underlying the association. Physical activity and social participation are identified as core input factors in health and hence are relevant to health policies for older adults (Ohrnberger et al., 2017; World Health Organization, 2009). While some studies have suggested that physical activity and social participation are protective factors of physical (Chmelo et al., 2015; Miszko et al., 2003; Serra-Rexach et al., 2011; Vusirikala et al., 2019) and cognitive (Fratiglioni et al., 2004; Nelson et al., 2013) health in later life, it is unclear whether these two lifestyle factors can mediate the relationship between physical and cognitive function. Against this backdrop, understanding these potential mediating effects is important for the design of policies for healthy aging.

We hypothesize that physical activity could be a mediator between physical and cognitive function due to the potential reciprocal association between physical activity and physical function and the potential reciprocal association between physical activity and cognitive function. With regard to the former association (i.e., the potential reciprocal association between physical activity and physical function), past evidence has suggested a protective effect of physical activity on physical function (Chmelo et al., 2015; Miszko et al., 2003; Serra-Rexach et al., 2011), and moderate or good physical function may serve as a precondition for leading a physically active lifestyle (Krall et al., 2014). With regard to the latter association (i.e., the potential reciprocal association between physical activity and cognitive function), the existing research has shown a positive bidirectional relationship between the physically active lifestyle and cognition, particularly executive function, in older adults (Daly et al., 2014). The increase in cognitive reserve and the reduction in vascular diseases may be pathways from physical activity to cognition in later life (Fratiglioni et al., 2004). In light of the previous evidence, it is reasonable to assume physical activity to be a mediator in the bidirectional association between physical and cognitive function. However, a recent study failed to corroborate such a mediating role of physical activity (Best et al., 2016). A possible explanation is that the recent study only relied on the self-reported time spent walking as the physical activity indicator, which was too simplistic to capture the global physical activity containing all workouts and incidental physical activities.

In addition to physical activity, social participation—that is, the engagement in activities that involve interactions with others in society or community (Oshio & Kan, 2019)—is considered as another behavioral factor closely associated with late-life health. Despite the various concepts of "social participation" in the past literature, we limit "social participation" to the engagement in social and mental activities in the present study. According to prior research, it is possible that social participation and physical function influence each other. A previous study found that people with a higher frequency of social participation in midlife had better physical performance in older ages and thus suggested a protective effect of social participation against physical function limitations (Vusirikala et al., 2019). Moreover, medical researchers usually view having physical function limitations as a factor restricting social participation (Ness et al., 2006). With respect to the association between social participation and cognitive function, previous evidence has shown a reciprocal relationship between social participation and cognitive function in older adults. According to Bosma et al. (2002), the elderly who engaged in mental (e.g., chess and puzzles) and social (e.g., club) activities at baseline tended to have a slower subsequent cognitive decline. Conversely, the elderly with higher levels of baseline cognitive function was more likely to involve mental and social activities during the follow-up. Therefore, given the potential reciprocal association between social participation and physical function and the potential reciprocal association between social participation and cognitive function, we postulate that social participation could be another mechanism underlying the bidirectional association between the two functional domains in later life.

Method

Data and Sample

The data used in this study were drawn from three waves of the Chinese Longitudinal Healthy Longevity Survey (CLHLS) in 2008/2009 (T1), 2011/2012 (T2), and 2014 (T3). The survey randomly selected half of the counties in 22 out of 31 provinces in mainland China, whose populations together constitute about 85% of the total national population. The CLHLS aims to interview all centenarians in the sampled counties/cities and collect a roughly equal number of respondents by sex in each single year of age from 65 to 99. The response rate was over 95% at each wave (Gu et al., 2019). A detailed description of the sampling design and data quality assessments for the CLHLS can be found elsewhere (Zeng, 2012).

In this study, we only selected survey participants who were at least 65 years old with complete assessments on the variables of interest (i.e., physical function, cognitive function, physical activity, and social participation) at all the three waves. Additionally, individuals with severe cognitive impairment (Mini-Mental State Exam [MMSE] score < 10) at baseline (Gu et al., 2019) were excluded due to the potential biases in their self-reported information, which is a common approach to restricting sample in some prior studies (e.g., Best et al., 2016; Krall et al., 2014; Mielke et al., 2013; Stijntjes et al., 2017; Tian et al., 2016). With the above criteria, we retained 4232 participants in the analytic sample for the main analysis (see Supplemental Figure 1). To handle missing data on covariates at T2, we performed multiple imputation on longitudinal data by chained equations and combined the results across 20 imputations using standard formulas (Rubin, 1987).

Furthermore, as previously reported by Gottesman et al. (2014), we applied the inverse-probability-of-attrition weighting (IPAW) method to attenuate the bias due to selective attrition (i.e., loss to follow-up and death). First, we classified the participants at baseline into two types, including those who were alive and remained in the study at both the second and third waves (= 1) and the others (= 0). Then, we developed a logit regression of the dichotomized participant type on baseline participant characteristics, including physical function, cognitive function, age, age squared, sex, urban/rural residence, living arrangement, educational level, farmer or not, and province fixed-effects, to compute each person's censoring weight, which was constructed as the inverse of the predicted probability of being alive and remaining in the study during the follow-up (see Supplemental Table 1). Finally, to ensure the representativeness of the data as well as to mitigate the attrition bias, we calculated the final weight by multiplying the sampling weight factor by the censoring weight factor (i.e., final weight = sampling weight × censoring weight). The sampling weights were estimated by the CLHLS to match the age–sex–(urban/rural) residence distribution of the population aged 65 and older in the 22 provinces in 2008. After applying the final weights, the balancing test in Supplemental Table 1 suggests no substantial difference in initial characteristics between the two types of participants, supporting the effectiveness of utilizing the IPAW approach. In the end, the original sample size for the main analysis was 4232, and the weighted sample size adjusted by final weights was 14,042.

Measures

Outcome Variables and Key Predictors

Physical function and cognitive function were both outcome variables and key predictors in the cross-lagged panel models in our study. Physical function was assessed by the following three tests capturing older people's physical performance (Zeng et al., 2017): (1)

"Can the interviewee stand up from sitting in a chair without using hands?," (2) "Can the interviewee stand up to pick up a book from the floor?," and (3) "Can the interviewee turn around 360° without help?." The score for each test was a binary variable with "1" referring to "yes" and "0" referring to "no." The responses to the three tests displayed Cronbach's α of .805, and Loevinger's *H* coefficient for each item was greater than .6, suggesting an acceptable reliability (Taber, 2018) and a strong scalability (Mokken, 1971), respectively. We constructed a physical function index based on the confirmatory factor analysis of the three tests. The physical function index ranged from −0.53 to 0.26, with higher scores representing better physical performance capacity. This index explained 82.8% of the total variance and the factor loading for each item was greater than 0.6, indicating an acceptable validity (Acock, 2013).

Cognitive function was derived from the Chinese version of the MMSE (Cronbach's α = .95). All the subdomains of the MMSE score (i.e., orientation, registration, attention, calculation, recall, and language) were in line with the international standard (Zeng & Vaupel, 2002). The scale for the MMSE score ranged from 0 to 30, with higher scores representing more favorable global cognitive function. Supplemental Table 2 shows the detailed instruction from Zhang (2006) on how to generate the MMSE score.

Mediators

Physical activity and social participation are parallel mediators in our models. Physical activity was a composite *Z*-score measure of the following two questions: (1) "How often do you engage in personal outdoor activities?" and (2) "Do you do exercises regularly at present?." The answer to the former question was on a scale ranging from 1 to 5 (*1 = never; 2 = not every month, but sometimes; 3 = not every week, but at least once a month; 4 = not every day, but at least once a week; and 5 = every day or almost every day*) and the answer to the latter question was dichotomized with 1 denoting "yes" and 0 denoting "no" (Cronbach's α = .62). We summed the *Z*-scores of these two items to construct the physical activity indicator.

Social participation was generated from two items, including "playing cards and/or mahjong with others" and "attending organized social activities." As previously reported by Gu et al. (2019), we did not sum the items but grouped the participants into frequent involvement (= 1; if they participated in at least one of the two activities at least once a month) and infrequent or no involvement (= 0), because Cronbach's α for these two items was only .32.

Covariates

We included five time-constant covariates throughout the models: (1) sex, (2) ethnic group (Han Chinese vs. other), (3) years of schooling (none, 1–6 years, and more than 6 years), (4) main occupation before 60 years old (farmer vs. other), and (5) province fixed-effects. We also included seven time-varying covariates: (1) age, (2) urban/rural residence, (3) living arrangement (alone, co-reside with spouse only, co-reside with both spouse and child(ren), co-reside with child(ren) only, live in a skipped-generation household, live in a nursing home, and other or unknown), (4) insufficient financial support for daily expenses reported by the participants or their proxies, (5) smoking, (6) excessive drinking (consumed at least 200 g of liquor or 400 g of beer per day vs. other; Li & Zhang, 2015), and (7) the diagnoses of the following diseases reported by the participants or their proxies: heart disease (yes vs. no or unknown, the same afterward), hypertension, stroke, diabetes, and Parkinson's disease. In addition to the self- or proxy-reported information on hypertension, we also categorized participants with high systolic blood pressure measurements (≥140 mmHg) as suffering from hypertension. Moreover, one-period lagged (i.e., prior-wave) time-varying covariates were included in our models to avoid any possible contamination due to the reverse causality between covariates and outcome variables. Table 1 presents the sample characteristics for the measures of physical function, cognitive function, physical activity, social participation, and covariates.

Analytic Strategy

To explore the temporal relationship between physical and cognitive function, we utilized Stata 15.1 to conduct cross-lagged panel models (CLPMs). Compared to the LGCM we mentioned earlier, the CLPM excels in taking into account temporal orders of the measures and thus is more suitable for examining potential reciprocal associations. In each model, we applied the quasi-maximum likelihood estimation (QMLE) approach to make better estimations for nonnormally distributed variables (Hartwell et al., 2019). Moreover, the final weights we calculated for each participant were incorporated at each stage of our analysis.

To examine the potential reciprocal association between physical and cognitive function, we first employed a conventional CLPM, which can be regarded as a set of lagged dependent variable (LDV) regressions developed in the form of path analysis. The one-period lagged (i.e., prior wave) dependent variables we controlled for contribute to attenuating the omitted-variable bias due to unobserved confounders (Angrist & Pischke, 2009). Within the model system, physical function was regressed onto its lagged measure and the lagged measure of cognitive function, as was cognitive function. Building on the conceptual diagram in Figure 1, we focused on the direct effect of lagged physical function on the present cognitive function (denoted as a_1 and a_2) and the direct effect of lagged cognitive function on the present physical function (denoted as b_1 and b_2). To derive the average effects across the whole time period, we further constrained the coefficients with the same meaning in two timespans to be equal (Li & Zhang, 2015), that is, we set $a_1 = a_2$, $b_1 = b_2$, $\gamma_1 = \gamma_2$, $\eta_1 = \eta_2$, and $\theta_1 = \theta_2$, which simplified the model system but did not compromise the results, and made our analysis more comparable to the existing research (e.g., Krall et al., 2014; Stijntjes et al., 2017; Tian et al., 2016).

Next, we investigated the potential bidirectional association between physical and cognitive change based on the conceptual diagram shown in Figure 2. Following Best et al. (2016), we aimed to answer whether a change in physical function could lead to a

Table 1. Sample Characteristics of the CLHLS 2008/2009 (T1), 2011/2012 (T2), and 2014 (T3), Weighted by the Final Weights (n = 4232, Weighted n = 14,042).

	T1	T2	T3
	Mean (*SD*) or %		
Physical function (−0.53 to 0.26)	0.20 (0.18)	0.18 (0.20)	0.13 (0.25)
Stand up from a chair without using hands (%)	90.26	90.26	84.55
Pick up a book from floor (%)	91.07	88.59	81.31
Turn around 360° (%)	93.19	90.66	86.07
Cognitive function [MMSE score] (0–30)	27.49 (3.30)	26.85 (4.36)	26.13 (5.36)
Cognitive impairment (%)	3.47	6.17	9.26
Physical activity (−2.34 to 2.05)	0.12 (1.63)	0.31 (1.72)	0.03 (1.77)
Regular exercise (%)	41.35	50.71	42.33
Outdoor activities (1–5)	3.77 (1.65)	3.77 (1.69)	3.58 (1.76)
Social participation (%)	29.13	27.58	25.89
Play cards/mahjong (%)	20.69	19.68	18.76
Attend organized social activities (%)	12.65	11.43	10.96
Age (65–111)	73.06 (6.24)	76.09 (6.25)	78.93 (6.27)
Sex (Male %)	48.32	48.32	48.32
Ethnicity (Han Chinese %)	94.63	94.63	94.63
Residence (Urban %)	42.46	56.21	61.36
Living arrangement (%)			
Alone	14.22	15.65	17.16
Co-reside with spouse only	37.33	31.18	29.14
Co-reside with both spouse and child(ren)	19.21	19.08	16.17
Co-reside with child(ren) only	22.61	26.45	29.56
Skipped-generation household	3.67	3.39	2.92
Nursing home	0.83	1.15	1.30
Other or unknown	2.11	3.10	3.74
Years of schooling			
No formal education	41.77	41.77	41.77
1–6 years	39.52	39.52	39.52
More than 6 years	18.71	18.71	18.71
Occupation (Farmer %)	62.65	62.65	62.65
Insufficient financial support (%)	21.52	23.61	19.52
Smoking (%)	24.45	22.53	20.07
Excessive drinking (%)	4.37	4.03	5.36
Heart disease (%)	11.38	14.79	16.95

(Continued)

Table 1. Continued

	T1	T2	T3
	Mean (*SD*) or %		
Hypertension (%)	76.22	76.90	78.24
Stroke (%)	6.28	8.55	11.68
Diabetes (%)	4.16	6.11	8.46
Parkinson's disease (%)	0.12	0.74	1.08

Note. CLHLS = Chinese Longitudinal Healthy Longevity Survey; MMSE = Mini-Mental State Exam.

subsequent change in cognitive function and vice versa. The early change in a functional domain was constructed as the difference between the functional measures at T2 and T1, and the late change in a functional domain equaled the difference between the functional measures at T3 and T2. Within the model system regarding physical and cognitive change, we focused on the direct effects of baseline physical or cognitive function on the early (i.e., *c* and *f*) and the late change (i.e., *d* and *g*) in the alternate functional domain and the direct effect of the early change in physical or cognitive function on the late change in the alternate functional domain (i.e., *e* and *h*).

Then we estimated the indirect effect of physical performance on cognition and vice versa. Additionally, we treated physical activity and social participation as potential mediators. Figure 3 shows the conceptual diagram of the CLPM with direct and

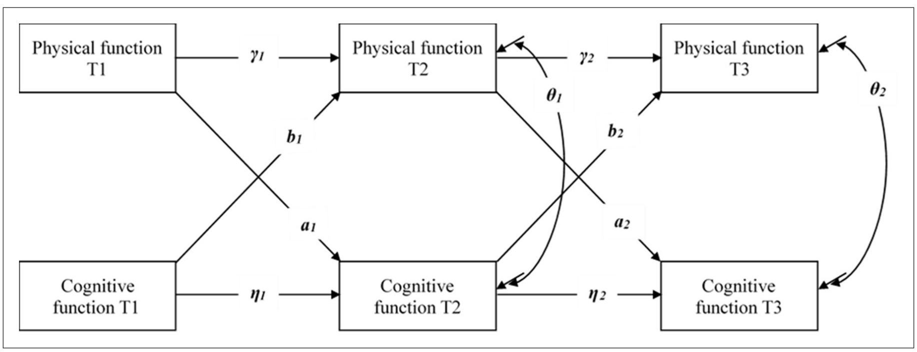

Figure 1. Conceptual diagram of cross-lagged associations between physical and cognitive function. *Note.* The time-constant controls include sex, ethnic group, years of schooling, main occupation before 60 years old, and province fixed-effects. The time-varying controls include one-period lagged age, urban/rural residence, living arrangement, insufficient financial support, smoking, excessive drinking, and diagnoses of heart disease, hypertension, stroke, diabetes, and Parkinson's disease. The same covariates were controlled for in the models in Figures 2 and 3.

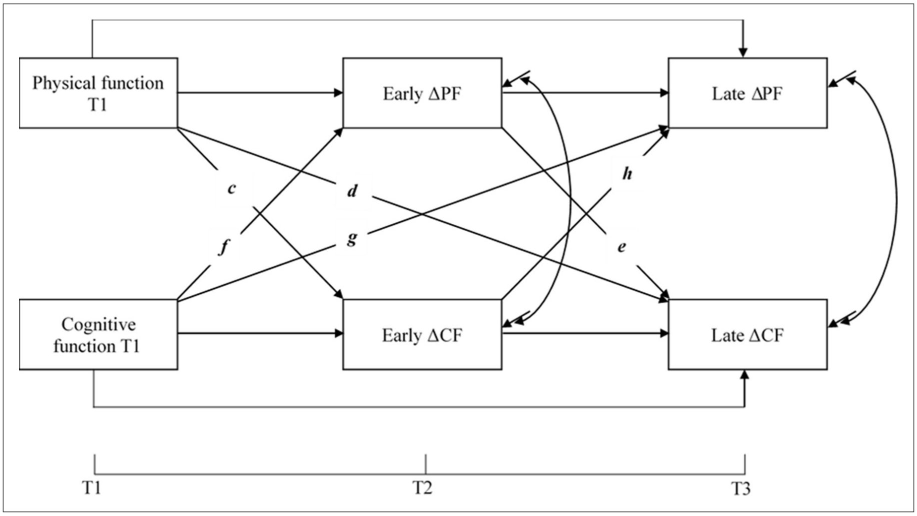

Figure 2. Conceptual diagram of cross-lagged associations between changes in physical and cognitive function. *Note*. PF = physical function; CF = cognitive function. Early ΔPF = $PF_{T2} - PF_{T1}$; early ΔCF = $CF_{T2} - CF_{T1}$; late ΔPF = $PF_{T3} - PF_{T2}$; and late ΔCF = $CF_{T3} - CF_{T2}$.

indirect effects using three waves of data, which is a conventional method of mediation analysis using longitudinal data (Little et al., 2007; Swart et al., 2011). The total effect of one function at baseline (T1) on the other function at T3 was decomposed into the direct effect of one function on the other function and the indirect effect of one function on the other function through physical activity and social participation at T2. In addition, we allowed the error terms of the equations examining the parallel mediators (i.e., physical activity and social participation) to be intercorrelated so as to mitigate the bias due to the common unobserved confounders.

Finally, we performed four sets of sensitivity analyses to check the robustness of our findings. We first explored whether we could obtain similar findings if we excluded individuals with baseline cognitive impairment (n = 259). The thresholds of cognitive impairment for the elderly Chinese with no education, medium educational attainment (1–6 years of schooling), and high educational attainment (more than 6 years of schooling) were MMSE score <18, <21, and <25, respectively (Zhu et al., 2017). Second, we excluded individuals with the lowest baseline physical performance scores (n = 144). Third, we imputed missing values of the variables of interest (i.e., physical function, cognitive function, physical activity, and social participation) at T2 and T3 using multiple imputation (m = 20) to mitigate the potential bias due to the differences between completers (i.e., the participants who completed all the assessments) and non-completers. Finally, given that the physical function indicator only captured the low-end physical performance capacities, we reconstructed an alternate measure by extracting three more items from the instrumental activities of daily living (IADL)

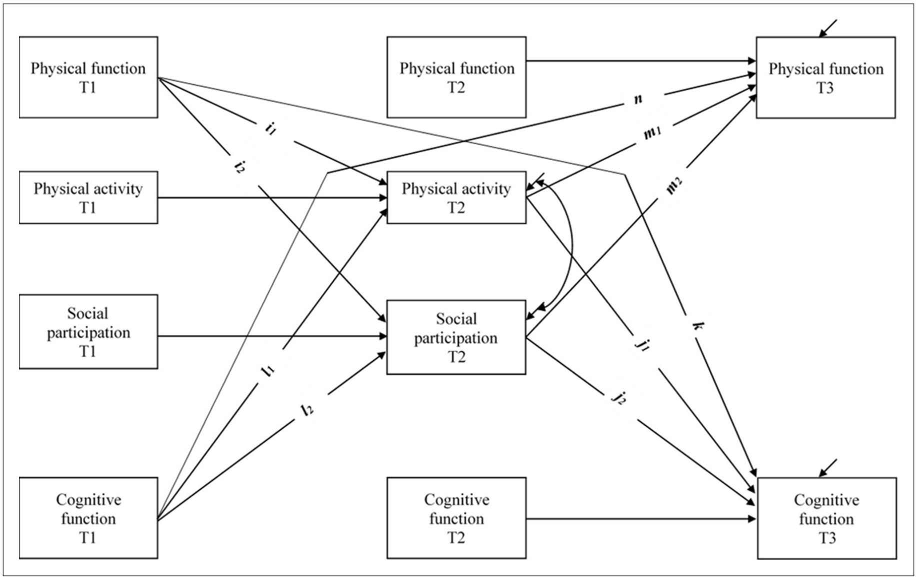

Figure 3. Conceptual diagram of the mediating effects of physical activity and social participation in cross-lagged associations between physical and cognitive function.

scale and using a confirmatory factor analysis to combine them with the three items we used earlier. These additional items were the participants' or their proxies' responses to the following three questions: (1) "Can you (i.e., the interviewee) walk continuously for 1 kilometer by yourself?" (*1 = yes, 0 = no, the same afterward*), (2) "Can you lift 5 kilograms, which is similar to a heavy bag of groceries?", and (3) "Can you continuously crouch and stand up for three times?". Cronbach's α for the six items was 0.88.

Results

Table 1 shows the summary statistics by wave. The mean physical function score decreased from 0.20 at baseline (T1) to 0.13 at T3, and the means at T1 and T3 were 0.30 pooled standard deviations apart (i.e., Cohen's d = .30). As suggested by Cohen (1988, p. 25), this difference is not negligible (Cohen's d > .2). Translating the difference into actual change in physical performance, the proportions of the participants who could stand up from a chair without using hands, pick up a book from floor, and turn around 360° without help decreased from 90.26%, 91.07%, and 93.19% at T1 to 84.55%, 81.31%, and 86.07% at T3, respectively. The mean cognitive function score decreased from 27.49 at T1 to 26.13 at T3, and the difference between the means at T1 and T3 was 0.31 pooled standard deviations. More specifically, the percentage of the participants with cognitive impairment increased from 3.47% at T1 to 9.26% at T3. Moreover, the physical function scores across the three

Table 2. Cross-Lagged Associations Between Physical and Cognitive Function (n = 4232, Weighted n = 14,042).

	Coefficient		Standardized coefficient	
Path	Estimate	95% CI	Estimate	95% CI
$PF_{T1} \rightarrow CF_{T2}$ (a_1)	1.442*	[0.132, 2.752]	0.059*	[0.006, 0.112]
$CF_{T1} \rightarrow PF_{T2}$ (b_1)	0.0034†	[−0.0003, 0.0070]	0.055†	[−0.005, 0.116]
$PF_{T2} \rightarrow CF_{T3}$ (a_2)	3.458***	[2.161, 4.756]	0.129***	[0.082, 0.176]
$CF_{T2} \rightarrow PF_{T3}$ (b_2)	0.0047***	[0.0022, 0.0073]	0.082***	[0.036, 0.127]
$PF_{T-1} \rightarrow CF_{T}$ ($a_1 = a_2$)	2.492***	[1.426, 3.559]	0.096***[1]	[0.057, 0.136]
$CF_{T-1} \rightarrow PF_{T}$ ($b_1 = b_2$)	0.0045***	[0.0021, 0.0068]	0.071***[1]	[0.033, 0.108]

Note. PF = physical function; CF = cognitive function. Each of the letters in parentheses in the first column corresponds to the same letter in Figure 1. [1]The estimates refer to how many second-wave standard deviations the outcome variable at wave t will change per baseline standard deviation increase in the key predictor at wave $t − 1$. †$p < .1$, *$p < .05$, **$p < .01$, ***$p < .001$ (two-tailed tests based on robust standard errors).

waves were significantly different ($F(2, 12{,}696) = 92.29$, $p < .001$), as were the cognitive function scores ($F(2, 12{,}696) = 91.98$, $p < .001$), indicating substantial declines in both functional domains during the follow-up.

Table 2 presents the estimated cross-lagged associations between physical and cognitive function. We found that better physical performance at T1 was significantly associated with better cognition at T2, and better cognition at T1 was marginally significantly associated with better physical performance at T2. Likewise, physical or cognitive function at T2 was positively and significantly associated with the alternate functional domain at T3. Then we standardized the coefficients so as to compare the magnitudes of the associations over the two timespans. The standardized coefficient for path a_1/a_2, conditional on $a_1 \neq a_2$ and $b_1 \neq b_2$, refers to how many standard deviations cognitive function at T2/T3 will change per standard deviation increase in physical function at T1/T2. Similarly, the standardized coefficient for path b_1/b_2, conditional on $a_1 \neq a_2$ and $b_1 \neq b_2$, represents how many standard deviations physical function at T2/T3 will change per standard deviation increase in cognitive function at T1/T2. For example, cognitive function at T2 rose by 0.059 standard deviations with one standard-deviation increase in physical function at T1. To examine any potential difference in the magnitudes of the associations of one functional domain with the subsequent alternate functional domain between the two timespans, we further compared the two sets of standardized path coefficients, that is, the difference between the standardized coefficients for a_1 and a_2 and the difference between the standardized coefficients for b_1 and b_2, respectively. The estimates revealed a significantly increasing magnitude of the association between physical function and subsequent cognitive function over the two timespans ($p = .019$), that is, standardized a_2 is significantly larger than standardized a_1. However, we did not observe a significant difference in the magnitudes of the associations of cognitive function with subsequent physical function between the two timespans (p = .420), that is, standardized b_1 and standardized b_2 are similar in magnitude. The findings implied the possibility of an increasing impact of physical function on cognitive function with aging, but not vice versa.

Further, to derive the average effects across the whole time period so that our analysis is more comparable to previous research (e.g., Krall et al., 2014; Stijntjes et al., 2017; Tian et al., 2016), we constrained the coefficients with the same meaning in two timespans to be equal (i.e., $a_1 = a_2$ and $b_1 = b_2$), and the estimates demonstrated a positive reciprocal relationship between physical and cognitive function (see Table 2). To compare the magnitude of the association between physical function and subsequent cognitive function with that of the association between cognitive function and subsequent physical function, we computed the standardized coefficients conditional on $a_1 = a_2$ and $b_1 = b_2$. The standardized coefficients refer to how many second-wave standard deviations physical or cognitive function at the current wave will change per baseline standard deviation increase in the alternate functional domain at the prior wave. Specifically, the estimates revealed that with one-baseline-standard-deviation increase in physical function, subsequent cognitive function rose by 0.096 second-wave standard deviations. Similarly, with one-baseline-standard-deviation increase in cognitive function, subsequent physical function rose by 0.071 second-wave standard deviations. Moreover, the estimates demonstrated no substantial difference between these two standardized coefficients (p = .231) and thus showed no evidence that the predictive effect of physical performance on subsequent cognition was significantly larger than that of cognition on subsequent physical performance or vice versa.

Table 3 provides (1) the estimated associations between baseline physical or cognitive function and subsequent changes in the alternate functional domain (i.e., c or f and d or g) and (2) the estimated bidirectional association between physical and cognitive change (i.e., e and h). Baseline physical function was positively and significantly

Table 3. Cross-Lagged Associations Between Changes in Physical and Cognitive Function (n = 4232, Weighted n = 14,042).

	Coefficient		Standardized coefficient	
Path	Estimate	95% CI	Estimate	95% CI
$PF_{T1} \rightarrow$ Early ΔCF (c)	1.455*	[0.146, 2.765]	0.057*	[0.005, 0.108]
$PF_{T1} \rightarrow$ Late ΔCF (d)	4.036***	[2.241, 5.831]	0.145***	[0.081, 0.210]
Early $\Delta PF \rightarrow$ Late ΔCF (e)	3.122***	[1.938, 4.305]	0.137***	[0.086, 0.188]
$CF_{T1} \rightarrow$ Early ΔPF (f)	0.0034†	[−0.0003, 0.0070]	0.051†	[−0.005, 0.107]
$CF_{T1} \rightarrow$ Late ΔPF (g)	0.0051**	[0.0013, 0.0089]	0.068**	[0.018, 0.119]
Early $\Delta CF \rightarrow$ Late ΔPF (h)	0.0042***	[0.0018, 0.0066]	0.078***	[0.035, 0.122]

Note. PF = physical function; CF = cognitive function. Early $\Delta PF = PF_{T2} - PF_{T1}$, early $\Delta CF = CF_{T2} - CF_{T1}$, late $\Delta PF = PF_{T3} - PF_{T2}$, and late $\Delta CF = CF_{T3} - CF_{T2}$. †$p$ < .1, *p < .05, **p < .01, ***p < .001 (two-tailed tests based on robust standard errors).

Table 4. Mediating Effects on Physical and Cognitive Function (n = 4232, Weighted n = 14,042).

	(1)	(2)
Outcome	Cognitive function$_{T3}$	Physical function$_{T3}$
Predictor	Physical function$_{T1}$	Cognitive function$_{T1}$
Predictor → PA$_{T2}$ (i_1 or l_1)	0.935*** [0.483, 1.387]	0.0403*** [0.0179, 0.0628]
PA$_{T2}$ → Outcome (j_1 or m_1)	0.178*** [0.076, 0.281]	0.0133*** [0.0081, 0.0190]
Predictor → SP$_{T2}$ (i_2 or l_2)	−0.019 [−0.107, 0.069]	0.0060* [0.0013, 0.0107]
SP$_{T2}$ → Outcome (j_2 or m_2)	0.482** [0.142, 0.822]	0.0107 [−0.0066, 0.0280]
Indirect effect via PA ($i_1 \times j_1$ or $l_1 \times m_1$)	0.167** [0.041, 0.293]	0.00054** [0.00018, 0.00090]
Indirect effect via SP ($i_2 \times j_2$ or $l_2 \times m_2$)	−0.0093 [−0.0529, 0.0342]	0.00006 [−0.00005, 0.00018]
Direct effect (k or n)	1.910* [0.390, 3.430]	0.0034* [0.0000, 0.0068]
Total effect	2.068** [0.521, 3.614]	0.0040* [0.0005, 0.0075]
Proportion mediated by PA (%)	8.069* [0.514, 15.624]	13.358* [0.559, 26.158]
Proportion mediated by SP (%)	−0.450 [−2.615, 1.715]	1.584 [−1.421, 4.589]

Note. PA = physical activity; SP = social participation. 95% CIs are in square brackets. *p < .05, **p < .01, ***p < .001 (two-tailed tests based on robust standard errors).

associated with both the early and the late changes in cognitive function, suggesting that more favorable initial physical function was associated with a slower cognitive decline during the follow-up. Conversely, more favorable initial cognitive function was also related to a slower subsequent physical decline. Furthermore, physical and cognitive change was positively reciprocally associated, that is, a faster physical decline preceded a faster cognitive decline and vice versa. Additionally, in light of the statistically nonsignificant difference (p = .086) between the standardized coefficients for the association of physical change with subsequent cognitive change (i.e., 0.137) and the association of cognitive change with subsequent physical change (i.e., 0.078), there was no solid evidence that the predictive effect of physical change on subsequent cognitive change was significantly larger than that of cognitive change on subsequent physical change or vice versa.

Table 4 presents the mediation analyses on cognitive function and physical function in column (1) and column (2), respectively. The total effect of baseline physical function on cognitive function at T3 was decomposed into the direct effect of baseline physical performance on cognition at T3 (i.e., k) and the indirect effects of baseline physical performance on cognition at T3 through physical activity and social participation at T2 (i.e., $i_1 \times j_1$ and $i_2 \times j_2$, respectively). Similarly, we also estimated the direct effect of baseline cognitive function on physical function at T3 (i.e., n) and the indirect effects of baseline cognition on physical performance at T3 through physical activity and social participation at T2 (i.e., $l_1 \times m_1$ and $l_2 \times m_2$, respectively). In addition, we used the "nlcom" (nonlinear combinations of estimators) command in Stata to calculate the estimates and the robust standard errors of the indirect effects, which equaled the products of two path coefficients (Acock, 2013). The mediation analysis of cognitive function in column (1) shows that the effect of baseline physical function on cognitive function at T3 was significantly mediated by physical activity at T2. Specifically, better initial physical function was associated with a more physically active lifestyle at T2, which was further associated with better cognitive function at T3. The indirect effect through physical activity, the direct effect, and the total effect of initial physical function on subsequent cognitive function were all positive and statistically significant. The indirect effect via physical activity accounted for 8.1% of the total effect of physical function on cognitive function. By contrast, baseline physical function did not significantly predict social participation at T2 (i.e., −0.019 [−0.107, 0.069]), although social participation at T2 significantly predicted cognitive function at T3 (i.e., 0.482 [0.142, 0.822]). Therefore, there was no evidence that social participation mediated the effect of physical function on cognitive function. The mediation analysis of physical function in column (2) demonstrates that the indirect effect via physical activity, the direct effect, and the total effect were all positive and statistically significant. Physical activity partially mediated the effect of cognitive function on physical function, and the indirect effect through physical activity accounted for 13.4% of the total effect. By contrast, while baseline cognitive function significantly predicted social participation at T2 (i.e., 0.0060 [0.0013, 0.0107]), social participation at T2 did not significantly predict physical function at T3 (i.e., 0.0107 [−0.0066, 0.0280]). Thus, social participation did not mediate the effect of cognitive function on physical function, either.

Supplemental Tables 3–14 present four sets of sensitivity analyses by excluding participants, imputing data, or using an alternate measure of physical function (see Supplemental Material). All the results of the sensitivity analyses are very similar to those of the main analysis presented in Tables 2–4, which further strengthens the robustness of our findings.

Discussion

The present study reveals a reciprocal relationship between physical and cognitive function among Chinese older adults. That is, physical performance predicts subsequent cognition, and cognition also predicts subsequent physical performance. Moreover, older adults who showed a steeper physical decline over the first 3 years of the study demonstrated a steeper cognitive decline in the following 3 years. Similarly, cognitive decline was positively associated with subsequent physical decline. Our findings thus revealed a vicious cycle linking physical and cognitive decline in Chinese older adults. Deterioration in physical or cognitive function may trigger subsequent deterioration in the alternate functional domain. Conversely, on a more positive note, late-life cognitive decline may be prevented by preserving physical function and vice versa.

In comparison with the study by Best et al. (2016), which assessed physical activity only by the time spent walking, we constructed a more generalized measurement of physical activity, whereby we further confirmed physical activity as a mediator in the bidirectional association between physical and cognitive function. Specifically, older adults with less favorable physical or cognitive function tended to be more physically sedentary and subsequently suffered from a faster decline in the alternate functional domain. It is worth noting that some research has confirmed the positive impact of physical activity on physical and cognitive function in late adulthood. Recent randomized controlled trial (RCT) studies have supported the protective effect of physical activity on physical function in later life, indicating that exercise training interventions play a part in improving older adults' mobility and strength (Chmelo et al., 2015; Miszko et al., 2003; Serra-Rexach et al., 2011). Moreover, there has been accumulating evidence that leading a physically active lifestyle contributes to maintaining cardiovascular fitness and thus becomes a protective factor of the central nervous system (Hötting & Röder, 2013). Previous research demonstrated that individuals who performed high levels of physical activity were significantly protected against cognitive decline, and even low-to-moderate level exercise also showed a significant protective effect against cognitive impairment (Sofi et al., 2011). In sum, promoting older people's performance of physical activity could be a key measure to healthy aging due to its protective effects against physical and cognitive impairments.

In line with the findings of Bosma et al. (2002), our results revealed a reciprocal association between social participation and cognitive function. Nonetheless, we found no evidence that physical function was associated with social participation in any direction. Therefore, social participation did not seem to be a mediator between physical and cognitive function in our analysis. There are two explanations for why social participation was not found to be a significant mediator. The first reason may be that we did not obtain a comprehensive measure capturing sufficient domains of social participation. Following the previous studies drawing on the CLHLS (e.g., Gu et al., 2019; Li & Zhang, 2015), we restricted social participation to the engagement in mental and social activities only, including playing cards/mahjong with others and attending organized social activities. While these activities may be helpful to develop cognitive reserve by strengthening the functioning and plasticity of neural circuits (Cheng, 2016), they may not contribute to improving or maintaining physical function. As shown in the existing RCT research, only engaging in the activities closely related to exercise or incidental physical activities, such as participating in community sports clubs (Levy et al., 2020) or voluntary services (Hong & Morrow-Howell, 2010), can effectively delay the onset of physical decline in older adults. However, these variables are not available from the CLHLS data. Since neither of the two types of social participation in our study requires particular physical activeness, it is understandable that they yield no protective effect on physical function. With regard to the determinants of playing cars or mahjong and attending organized social activities in older adults, we found that people engaged in these two activities depending mainly on certain sociodemographic characteristics, such as age, ethnic group, educational attainment, and living arrangement, but not on physical function. Second, it is possible that only long-term social participation can significantly affect physical function. For instance, a prior study suggested that the frequency of social participation in midlife was positively associated with physical function in older ages, and better physical performance in late adulthood was observed only if higher levels of social participation persisted over time (Vusirikala et al., 2019).

Our study has two major strengths. First, drawing on nationally representative longitudinal data in China, we are the very first few to investigate the cross-lagged associations between late-life physical and cognitive function in the setting of developing countries. In this way, our study broadens the understanding of the interrelationship between physical and cognitive function in the aging process. Second, we evaluated the potential mechanisms underlying the reciprocal relationship between physical and cognitive function and found physical activity to be a mediator, which could further contribute to health interventions.

This study also has some limitations. First, the physical activity indicator did not classify different types of exercise and incidental activities due to the limited measurements provided by the CLHLS. Past research has reported different impacts of aerobic exercise and resistance exercise on physical and cognitive health. For example, while both aerobic exercise and resistance exercise are beneficial to protecting physical function, each has its own merits in specific subdomains of physical function (Chmelo et al., 2015). Additionally, aerobic exercise is better at supporting cognitive reserve than resistance exercise (Cheng, 2016). Therefore, further research needs to suggest a more comprehensive physical activity arrangement to effectively break the vicious cycle linking physical and cognitive decline. Second, following Gu et al. (2019), to avoid the bias due to low reliability, we did not create a composite index for social participation by summing the two items assessing the frequencies of playing cards/mahjong and attending organized social activities, respectively, but constructed a binary social participation indicator. Admittedly, dichotomizing the indicator might lose some information, thereby underestimating the mediating effects and reducing the statistical power (Altman & Royston, 2006). However, even if we tested the mediating effect of each of the two items of social participation separately (i.e., the frequency of playing cards/mahjong on a scale from 1 to 5 and the frequency of attending organized social activities on a scale from 1 to 5), we did not find playing cards/mahjong or attending organized social activities to be a significant mediator between physical and cognitive function. Further research should generate more reliable and detailed measures capturing myriad domains of social participation.

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Supplemental Material

Supplemental material for this article is available online.

References

Acock, A. C. (2013). *Discovering structural equation modeling using Stata* (Rev. ed.). Stata Press.

Alfaro-Acha, A., Al Snih, S., Raji, M. A., Kuo, Y.-F., Markides, K. S., & Ottenbacher, K. J. (2006). Handgrip strength and cognitive decline in older Mexican Americans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *61*(8), 859–865. https://doi.org/10.1093/gerona/61.8.859

Altman, D. G., & Royston, P. (2006). The cost of dichotomising continuous variables. *BMJ*, *332*(7549), 1080–1080. https://doi.org/10.1136/bmj.332.7549.1080

Angrist, J. D., & Pischke, J.-S. (2009). *Mostly harmless econometrics: An empiricist's companion*. Princeton University Press.

Atkinson, H. H., Rapp, S. R., Williamson, J. D., Lovato, J., Absher, J. R., Gass, M., Henderson, V. W., Johnson, K. C., Kostis, J. B., Sink, K. M., Mouton, C. P., Ockene, J. K., Stefanick, M. L., Lane, D. S., & Espeland, M. A. (2010). The relationship between cognitive function and physical performance in older women: Results from the women's health Initiative memory study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *65A*(3), 300–306. https://doi.org/10.1093/gerona/glp149

Barker, D. H., Rancourt, D., & Jelalian, E. (2014). Flexible models of change: Using structural equations to match statistical and theoretical models of multiple change processes. *Journal of Pediatric Psychology*, *39*(2), 233–245. https://doi.org/10.1093/jpepsy/jst082

Best, J. R., Liu-Ambrose, T., Boudreau, R. M., Ayonayon, H. N., Satterfield, S., Simonsick, E. M., Studenski, S., Yaffe, K., Newman, A. B., Rosano, C., Study, B. C., & Health, Aging and Body Composition Study. (2016). An evaluation of the longitudinal, bidirectional associations between gait speed and cognition in older women and men. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *71*(12), 1616–1623. https://doi.org/10.1093/gerona/glw066

Bishop, N. J., Eggum-Wilkens, N. D., Haas, S. A., & Kronenfeld, J. J. (2016). Estimating the co-development of cognitive decline and physical mobility limitations in older U.S. adults. *Demography*, *53*(2), 337–364. https://doi.org/10.1007/s13524-016-0458-x

Bosma, H., van Boxtel, M. P. J., Ponds, R. W. H. M., Jelicic, M., Houx, P., Metsemakers, J., & Jolles, J. (2002). Engaged lifestyle and cognitive function in middle and old-aged, non-demented persons: A reciprocal association? *Zeitschrift für Gerontologie und Geriatrie*, *35*(6), 575–581. https://doi.org/10.1007/s00391-002-0080-y

Boyle, P. A., Buchman, A. S., Wilson, R. S., Leurgans, S. E., & Bennett, D. A. (2009). Association of muscle strength with the risk of Alzheimer disease and the rate of cognitive decline in community-dwelling older persons. *Archives of Neurology*, *66*(11), 1339–1344. https://doi.org/10.1001/archneurol.2009.240

Cheng, S.-T. (2016). Cognitive reserve and the prevention of dementia: The role of physical and cognitive activities. *Current Psychiatry Reports*, *18*(9), 85. https://doi.org/10.1007/s11920-016-0721-2

Chmelo, E. A., Crotts, C. I., Newman, J. C., Brinkley, T. E., Lyles, M. F., Leng, X., Marsh, A. P., & Nicklas, B. J. (2015). Heterogeneity of physical function responses to exercise training in older adults. *Journal of the American Geriatrics Society*, *63*(3), 462–469. https://doi.org/10.1111/jgs.13322

Clouston, S. A. P., Brewster, P., Kuh, D., Richards, M., Cooper, R., Hardy, R., Rubin, M. S., & Hofer, S. M. (2013). The dynamic relationship between physical function and cognition in longitudinal aging cohorts. *Epidemiologic Reviews*, *35*(1), 33–50. https://doi.org/10.1093/epirev/mxs004

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Erlbaum Associates.

Daly, M., McMinn, D., & Allan, J. L. (2014). A bidirectional relationship between physical activity and executive function in older adults. *Frontiers in Human Neuroscience*, *8*(1044), 1044. https://doi.org/10.3389/fnhum.2014.01044

Deary, I. J., Johnson, W., Gow, A. J., Pattie, A., Brett, C. E., Bates, T. C., & Starr, J. M. (2011). Losing one's grip: A bivariate growth curve model of grip strength and nonverbal rReasoning from age 79 to 87 years in the Lothian birth cohort 1921. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *66B*(6), 699–707. https://doi.org/10.1093/geronb/gbr059

Dias, J. M. (2014). Physical functioning. In A. C. Michalos (Ed.), *Encyclopedia of quality of life and well-being research* (pp. 4793–4795). Springer.

Dodge, H. H., Kadowaki, T., Hayakawa, T., Yamakawa, M., Sekikawa, A., & Ueshima, H. (2005). Cognitive impairment as a strong predictor of incident disability in specific ADL-IADL tasks among community-dwelling elders: The Azuchi study. *The Gerontologist*, *45*(2), 222–230. https://doi.org/10.1093/geront/45.2.222

Fratiglioni, L., Paillard-Borg, S., & Winblad, B. (2004). An active and socially integrated lifestyle in late life might protect against dementia. *The Lancet Neurology*, *3*(6), 343–353. https://doi.org/10.1016/S1474-4422(04)00767-7

Gale, C. R., Allerhand, M., Sayer, A. A., Cooper, C., & Deary, I. J. (2014). The dynamic relationship between cognitive function and walking speed: The English longitudinal study of ageing. *AGE*, *36*(4), 9682. https://doi.org/10.1007/s11357-014-9682-8

Gatz, M., Reynolds, C. A., Finkel, D., Pedersen, N. L., & Walters, E. (2010). Dementia in Swedish twins: Predicting incident cases. *Behavior Genetics*, *40*(6), 768–775. https://doi.org/10.1007/s10519-010-9407-4

Goins, R. T., & Pilkerton, C. S. (2010). Comorbidity among older American Indians: The native elder care study. *Journal of Cross-Cultural Gerontology*, *25*(4), 343–354. https://doi.org/10.1007/s10823-010-9119-5

Gottesman, R. F., Rawlings, A. M., Sharrett, A. R., Albert, M., Alonso, A., Bandeen-Roche, K., Coker, L. H., Coresh, J., Couper, D. J., Griswold, M. E., Heiss, G., Knopman, D. S., Patel, M. D., Penman, A. D., Power, M. C., Selnes, O. A., Schneider, A. L. C., Wagenknecht, L. E., Windham, B. G., . . .Mosley, T. H. (2014). Impact of differential attrition on the association of education with cognitive change over 20 years of follow-up: The ARIC neurocognitive study. *American Journal of Epidemiology*, *179*(8), 956–966. https://doi.org/10.1093/aje/kwu020

Gu, D., Feng, Q., & Yeung, W.-J. J. (2019). Reciprocal dynamics of solo-living and health among older adults in contemporary China. *The Journals of Gerontology: Series B*, *74*(8), 1441–1452. https://doi.org/10.1093/geronb/gby140

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New England Journal of Medicine*, *332*(9), 556–562. https://doi.org/10.1056/NEJM199503023320902

Hartwell, M. L., Khojasteh, J., Wetherill, M. S., Croff, J. M., & Wheeler, D. (2019). Using structural equation modeling to examine the influence of social, behavioral, and nutritional variables on health outcomes based on NHANES data: Addressing complex design, non-normally distributed variables, and missing information. *Current Developments in Nutrition*, *3*(5), nzz010. https://doi.org/10.1093/cdn/nzz010

Hong, S. I., & Morrow-Howell, N. (2010). Health outcomes of experience corps: A high-commitment volunteer program. *Social Science & Medicine*, *71*(2), 414–420. https://doi.org/10.1016/j.socscimed.2010.04.009

Hötting, K., & Röder, B. (2013). Beneficial effects of physical exercise on neuroplasticity and cognition. *Neuroscience & Biobehavioral Reviews*, *37*(9 Pt B), 2243–2257. https://doi.org/10.1016/j.neubiorev.2013.04.005

Inzitari, M., Newman, A. B., Yaffe, K., Boudreau, R., de Rekeneire, N., Shorr, R., Harris, T. B., & Rosano, C. (2007). Gait speed predicts decline in attention and psychomotor speed in older adults: The health aging and body composition study. *Neuroepidemiology*, *29*(3-4), 156–162. https://doi.org/10.1159/000111577

Kelman, H. R., Thomas, C., Kennedy, G. J., & Cheng, J. (1994). Cognitive impairment and mortality in older community residents. *American Journal of Public Health*, *84*(8), 1255–1260. https://doi.org/10.2105/AJPH.84.8.1255

Kiely, K. M. (2014). Cognitive function. In A. C. Michalos (Ed.), *Encyclopedia of quality of life and well-being research* (pp. 974–978). Springer.

Krall, J. R., Carlson, M. C., Fried, L. P., & Xue, Q.-L. (2014). Examining the dynamic, bidirectional associations between cognitive and physical functioning in older adults. *American Journal of Epidemiology*, *180*(8), 838–846. https://doi.org/10.1093/aje/kwu198

Levy, S. S., Thralls, K. J., Goble, D. J., & Krippes, T. B. (2020). Effects of a community-based exercise program on older adults' physical function, activities of daily living, and exercise self-efficacy: Feeling Fit Club. *Journal of Applied Gerontology*, *39*(1), 40–49. https://doi.org/10.1177/0733464818760237

Li, T., & Zhang, Y. (2015). Social network types and the health of older adults: Exploring reciprocal associations. *Social Science & Medicine*, *130*, 59–68. https://doi.org/10.1016/j.socscimed.2015.02.007

Little, T. D., Preacher, K. J., Selig, J. P., & Card, N. A. (2007). New developments in latent variable panel analyses of longitudinal data. *International Journal of Behavioral Development*, *31*(4), 357–365. https://doi.org/10.1177/0165025407077757

Mielke, M. M., Roberts, R. O., Savica, R., Cha, R., Drubach, D. I., Christianson, T., Pankratz, V. S., Geda, Y. E., Machulda, M. M., Ivnik, R. J., Knopman, D. S., Boeve, B. F., Rocca, W. A., & Petersen, R. C. (2013). Assessing the temporal relationship between cognition and gait: Slow gait predicts cognitive decline in the Mayo clinic study of aging. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *68*(8), 929–937. https://doi.org/10.1093/gerona/gls256

Miszko, T. A., Cress, M. E., Slade, J. M., Covey, C. J., Agrawal, S. K., & Doerr, C. E. (2003). Effect of strength and power training on physical function in community-dwelling older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *58*(2), M171–M175. https://doi.org/10.1093/gerona/58.2.M171

Mokken, R. J. (1971). *A theory and procedure of scale analysis: With applications in political research*. De Gruyter.

Nelson, L. A., Noonan, C. J., Goldberg, J., & Buchwald, D. S. (2013). Social engagement and physical and cognitive health among American Indian participants in the Health and Retirement Study. *Journal of Cross-Cultural Gerontology*, *28*(4), 453–463. https://doi.org/10.1007/s10823-013-9213-6

Ness, K. K., Wall, M. M., Oakes, J. M., Robison, L. L., & Gurney, J. G. (2006). Physical performance limitations and participation restrictions among cancer survivors: A population-based study. *Annals of Epidemiology*, *16*(3), 197–205. https://doi.org/10.1016/j.annepidem.2005.01.009

Ohrnberger, J., Fichera, E., & Sutton, M. (2017). The relationship between physical and mental health: A mediation analysis. *Social Science & Medicine*, *195*, 42–49. https://doi.org/10.1016/j.socscimed.2017.11.008

Oshio, T., & Kan, M. (2019). Which is riskier for mental health, living alone or not participating in any social activity? Evidence from a population-based eleven-year survey in Japan. *Social Science & Medicine*, *233*, 57–63. https://doi.org/10.1016/j.socscimed.2019.05.049

Rowe, J. W., & Kahn, R. L. (1997). Successful aging. *The Gerontologist*, *37*(4), 433–440. https://doi.org/10.1093/geront/37.4.433

Rubin, D. B. (1987). *Multiple imputation for nonresponse in surveys*. Wiley.

Serra-Rexach, J. A., Bustamante-Ara, N., Hierro Villarán, M., González Gil, P., Sanz Ibáñez, M. J., Blanco Sanz, N., Ortega Santamaría, V., Gutiérrez Sanz, N., Marín Prada, A. B., Gallardo, C., Rodríguez Romo, G., Ruiz, J. R., & Lucia, A. (2011). Short-term, light- to moderate-intensity exercise training improves leg muscle strength in the oldest old: A randomized controlled trial. *Journal of the American Geriatrics Society*, *59*(4), 594–602. https://doi.org/10.1111/j.1532-5415.2011.03356.x

Shetty, P. (2012). Grey matter: Ageing in developing countries. *The Lancet*, *379*(9823), 1285–1287. https://doi.org/10.1016/S0140-6736(12)60541-8

Sofi, F., Valecchi, D., Bacci, D., Abbate, R., Gensini, G. F., Casini, A., & Macchi, C. (2011). Physical activity and risk of cognitive decline: A meta-analysis of prospective studies. *Journal of Internal Medicine*, *269*(1), 107–117. https://doi.org/10.1111/j.1365-2796.2010.02281.x

Stijntjes, M., Aartsen, M. J., Taekema, D. G., Gussekloo, J., Huisman, M., Meskers, C. G. M., & Maier, A. B. (2017). Temporal relationship between cognitive and physical performance in middle-aged to oldest old people. *The Journals of Gerontology: Series A*, *72*(5), 662–668.

Studenski, S., Perera, S., Patel, K., Rosano, C., Faulkner, K., Inzitari, M., Brach, J., Chandler, J., Cawthon, P., Connor, E. B., Nevitt, M., Visser, M., Kritchevsky, S., Badinelli, S., Harris, T., Newman, A. B., Cauley, J., Ferrucci, L., & Guralnik, J. (2011). Gait speed and survival in older adults. *JAMA*, *305*(1), 50–58. https://doi.org/10.1001/jama.2010.1923

Swart, H., Hewstone, M., Christ, O., & Voci, A. (2011). Affective mediators of intergroup contact: A three-wave longitudinal study in South Africa. *Journal of Personality and Social Psychology*, *101*(6), 1221–1238. https://doi.org/10.1037/a0024450

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, *48*(6), 1273–1296. https://doi.org/10.1007/s11165-016-9602-2

Taekema, D. G., Ling, C. H. Y., Kurrle, S. E., Cameron, I. D., Meskers, C. G. M., Blauw, G. J., Westendorp, R. G. J., de Craen, A. J. M., & Maier, A. B. (2012). Temporal relationship between handgrip strength and cognitive performance in oldest old people. *Age and Ageing*, *41*(4), 506–512. https://doi.org/10.1093/ageing/afs013

Tian, Q., An, Y., Resnick, S. M., & Studenski, S. (2016). The relative temporal sequence of decline in mobility and cognition among initially unimpaired older adults: Results from the Baltimore longitudinal study of aging. *Age and Ageing*, *60*(3), 445–451. https://doi.org/10.1093/ageing/afw185

Vusirikala, A., Ben-Shlomo, Y., Kuh, D., Stafford, M., Cooper, R., & Morgan, G. S. (2019). Mid-life social participation and physical performance at age 60-64: Evidence from the 1946 British birth cohort study. *European Journal of Public Health*, *29*(5), 986–992. https://doi.org/10.1093/eurpub/ckz005

World Health Organization. (2009). *Global health risks: Mortality and burden of disease attributable to selected major risks*. World Health Organization. https://apps.who.int/iris/handle/10665/44203.

Zeng, Y. (2012). Towards deeper research and better policy for healthy aging using the unique data of chinese longitudinal healthy longevity survey. *China Economic Journal*, *5*(2-3), 131–149. https://doi.org/10.1080/17538963.2013.764677

Zeng, Y., Feng, Q., Hesketh, T., Christensen, K., & Vaupel, J. W. (2017). Survival, disabilities in activities of daily living, and physical and cognitive functioning among the oldest-old in China: A cohort study. *The Lancet*, *389*(10079), 1619–1629. https://doi.org/10.1016/S0140-6736(17)30548-2

Zeng, Y., & Vaupel, J. W. (2002). Functional capacity and self-evaluation of health and life of oldest old in China. *The Journal of Social Issues*, *58*(4), 733–748. https://doi.org/10.1111/1540-4560.00287

Zhang, Z. (2006). Gender differentials in cognitive impairment and decline of the oldest old in China. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(2), S107–S115. https://doi.org/10.1093/geronb/61.2.S107

Zhu, X., Qiu, C., Zeng, Y., & Li, J. (2017). Leisure activities, education, and cognitive impairment in Chinese older adults: A population-based longitudinal study. *International Psychogeriatrics*, *29*(5), 727–739. https://doi.org/10.1017/S1041610216001769

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