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# Associations of exercise, nutritional status, and smoking with cognitive decline among older adults in Taiwan: Results of a longitudinal population-based study

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ABSTRACT

This study aimed to explore the long-term effects of exercise, smoking, and nutritional status on cognitive reserve and changes in cognitive function among Taiwanese adults aged ≥65 years. Data were obtained from the Taiwan Longitudinal Study of Aging, a national representative population-based cohort study. Results showed that the average baseline scores on the Short Portable Mental Status Questionnaire (SPMSQ) and Mini-Nutritional Assessment (MNA) were 9.07 and 26.01, respectively. The proportions of smoking and exercising at baseline were 24.12% and 58.67%, respectively. A linear regression analysis indicated that old adults who were current and consistent exercisers had better subsequent 4-year SPMSQ scores than those who were not exercisers ($P < 0.05$). The MNA score was positively associated with subsequent 4- and 8-year SPMSQ scores for the 65–74-year-old adults ($P < 0.05$). The logistic regression analysis showed that current and consistent exercise was negatively associated with subsequent 4-year cognitive decline ($P < 0.05$). Previous exercise experience was positively associated with subsequent 8-year cognitive decline for the ≥75-year-old adults ($P < 0.05$). The MNA score was negatively correlated with subsequent 4- and 8-year cognitive decline among the 65–74-year-old adults. Among the adults aged ≥75 years, consistent smoking was positively associated with cognitive decline over 4 years ($P < 0.05$). Therefore, current and consistent exercise and good nutritional status benefit cognitive function and reserve, and have protective effects on cognitive decline among old adults, whereas discontinued exercise, poor nutrition, and cigarette smoking are likely to raise the risk of cognitive decline.

## 1. Introduction

Taiwan is a rapidly aging society. Among the general population, the proportion of adults aged ≥ 65 years were 11% in 2010, and it is expected to reach 20% in 2025 (Council for Economic Planning & Development, Taiwan, Rep. of China, 2008; Council of Labor Affairs, the Ministry of Interior, 2010); thus, age-related issues have started to raise many concerns. Almost 8% of people aged 65 years and over in Taiwan have cognitive impairment, ranging from mild deficits to dementia (Sun et al., 2014). Cognitive impairment and decline decrease the quality of life and increase mortality in the older adult population (Campos, Ferreira e Ferreira, Vargas, & Albala, 2014; Meng & D'Arcy, 2013) and raise medical and social burdens. Therefore, it is essential to examine the factors related to early reserve cognitive function and the delay or prevention of cognitive impairment among older adults.

Multiple factors, such as genetics, medical disorder, childhood IQ, education, lifestyle, and diets, are potentially related to cognitive function in older adults (Alfred et al., 2014; Deary et al., 2009; Gow, Corley, Starr, & Deary, 2012). Lifestyle and nutrition are modifiable factors (Deary et al., 2009). Lifestyle factors include smoking and exercise habits. Studies that have investigated the associations between smoking habits and cognitive function found that cigarette smoking accelerated cognitive impairment and decline (Huang, Dong, Zhang, Wu, & Liu, 2009; Zhou et al., 2003). However, in contrast to smoking, exercise has been found to have beneficial effects on physical and mental health (Cooper et al., 2011, 2014; Holstila, Mänty, Rahkonen, Lahelma, & Lahti, 2017; Loprinzi, 2016). Physical activity has been reported to be associated with cognitive function and negatively related to cognitive impairment and decline (Deary et al., 2009; Farina, Tabet, & Rusted, 2014; Huang et al., 2009; Lam et al., 2009). Older adults in Hong Kong who exercised regularly (> 5 years) had higher scores on cognitive tests (Lam et al., 2009). In another study, habitual physical activity was associated with the performance of executive functions of cognition in participants with a diagnosis of mild to moderate

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Alzheimer's disease (Farina et al., 2014). The results of a meta-analysis indicated that physical activities and fitness had beneficial effects on human cognition (Cooper et al., 2011; Deary et al., 2009; Sofi et al., 2011), but these effects might have been influenced by a number of factors, including consistency of exercise. Longitudinal studies on the influence of consistency of exercise on long-term changes in cognitive functions and cognitive reserve are rare (Cooper et al., 2011).

Nutritional status is also a modifiable factor in life. Studies of the association between nutritional status and cognitive function have reported finding worse nutritional status among older adults with cognitive impairment than in those without cognitive impairment (Dumont et al., 2005; Malara et al., 2014). However, the association between nutritional status and cognition might be bi-directional (Malara et al., 2014). Poor nutrition might also be a potential risk factor for cognitive decline in the older population (Guerin et al., 2005; Malara et al., 2014). The effects of nutritional status on cognitive function require further investigation.

Cognitive reserve and the prevention of cognitive decline from aging are essential in a rapidly aging society. Evaluations of the long-term effects of modifiable habits, including smoking, exercise, and nutritional status on cognitive reserve and changes in cognitive function are necessary, but limited in Taiwan. Most previous studies investigating the relationship between these factors and cognition tend to use cross-sectional designs or have short-term follow-up periods, and focus on only one or two specific and individual factors (Huang et al., 2009; Zhou et al., 2003). Few studies have analyzed older adults' nutritional status simultaneously. Therefore, this study explored the long-term effects of exercise, smoking, and nutritional status on cognitive reserve and changes in cognitive function in a population-based cohort of older adults aged 65 years and over.

## 2. Methods

### 2.1. Study design

Data for this study were obtained from the Taiwan Longitudinal Study on Aging (TLSA), a national cohort study. The TLSA, which was launched in 1989, uses a stratified multi-stage equal probability sampling method, with the township as the primary sampling unit (Hermalin, Liang, & Chang, 1989; Zimmer, Liu, Hermalin, & Chuang, 1998; Zimmer, Martin, & Chang, 2002). Trained researchers administered the TLSA questionnaires for in-home and in-person completion by the participants. The collected data included socio-demographic, health, and lifestyle information about the nearly-old and the older adults living in Taiwan. The TLSA collected nutritional and dietary data in 1999. Therefore, the present study used data from the 1999 survey as a baseline dataset, and data from the 2003 and 2007 surveys as the endpoints. Of the 4440 participants in 1999, 3778 and 3132 successfully completed the interview in 2003 and 2007, respectively. The TLSA was approved by Taiwanese government-appointed representatives. Informed consent was obtained from all participants. The present study was approved by the Institutional Review Board of I-Shou University.

### 2.2. Cognitive function

The Short Portable Mental Status Questionnaire (SPMSQ) was used to evaluate the cognitive function of the older adults who participated in the TLSA; it has been validated for use with older Taiwanese adults (Hsiao, Chiu, & Liu, 1994; Pfeiffer, 1975). The SPMSQ has 10 questions, including orientation to time and place, personal history, long-term and short-term memory, and calculations. The total SPMSQ score is calculated and ranges from 0 (worst) to 10 (best), with a high score indicating better cognitive function. The SPMSQ scores at baseline, the subsequent 4- and 8-year scores, and the changes in scores over 4 and 8 years were examined.

### 2.3. Lifestyle factors

Lifestyle factors included smoking, alcohol consumption, and exercising habits. Smoking and alcohol consumption were evaluated using the following questions: "Do you smoke?" and "Do you drink alcohol?" The response categories were "yes" and "no."

Exercise was evaluated using the following questions: "Do you usually exercise"? The response options were "no", "≤2 times/week," "3–5 times/week," and "≥6 times/week." The response options were collapsed into two categories: "no exercise (≤2 times/week)" and "exercise (≥3 times/week)".

Changes in lifestyle factors were examined. Participants who did not smoke cigarettes, drink alcohol, or exercise between 1999 and 2003 or between 1999 and 2007 were classified as "nonsmokers," "non-drinkers," and "not an exerciser," respectively. Those who did smoke, drink alcohol, or exercise habitually in 1999, but not in 2003 or 2007, were classified as a "past" smokers, drinkers, and exercisers, respectively. Conversely, those who did not smoke, drink alcohol, or exercise habitually in 1999, but who had these habits at the time of the study were classified as "current" smokers, drinkers, and exercisers, whereas those with smoking, drinking, and exercise habits between 1999 and 2003 or between 1999 and 2007 were classified as "consistent" smokers, drinkers, and exercisers.

### 2.4. Nutritional status

Nutritional status was assessed using the Mini-Nutritional Assessment (MNA) - Taiwan version II. The MNA consists of simple anthropometric measurements, global and dietary assessments, and subjective self-evaluations; it has been validated for use in samples of older Taiwanese adults by Tsai, Ku, and Tsai (2008). The total MNA score ranges from 0 to 30 points, with a higher score indicating better nutritional status.

### 2.5. Other factors

The other study variables included socio-demographic characteristics, functional abilities, and co-morbidities. **S**ocio-demographic characteristics included gender, age, and years of formal education. A basic questionnaire to measure Activities of Daily Living (ADL) was used to evaluate the study participants' functional abilities (Katz, Ford, Moskowitz, Jackson, & Jaffe, 1963). Comorbid conditions are assessed using a list of diseases and the total numbers of medical problems that participants report are calculated.

### 2.6. Analysis

Descriptive data were weight-adjusted for the sampling design. Chi-square tests and Student's t-tests were used to analyze differences in the distributions of the demographic data, lifestyle factors, ADL, SPMSQ, and MNA scores between the age groups (65–74 years and ≥75 years). To examine the effects of age on cognition, we stratified and reported our results by age group (65–74 and ≥75 years). Multivariate general linear regression model (GLM) and logistic regression analyses were performed to evaluate the associations of exercise, smoking, nutritional factors, with subsequent SPMSQ scores and cognitive decline, stratified by age groups after adjusting for confounding variables. Cognitive decline was defined as subsequent 4- and 8-year changes in SPMSQ scores (> 2 points). Confounding factors included gender, age, years of formal education, baseline ADL scores, and co-morbidities. Study participants with SPMSQ scores ≤ 2 points at baseline were excluded from the analysis (n = 48). The beta coefficients, adjusted odds ratios (aOR), and 95% confidential intervals (95% CI) were reported. The SAS software package (SAS Institute Inc., Cary, NC, USA) version 9.1 was used for all statistical analyses. Statistical significance was set as $P < 0.05$; probability levels of $P < 0.01$ and $P < 0.001$ were also reported.

**Table 1**
Characteristics of study participants in 1999[a,b].

| | All n = 2508 | 65-74 n = 1373 | ≥ 75 n = 1135 | P |
|---|---|---|---|---|
| Age (mean ± std) (y) | 73.28 ± 5.15 | 69.74 ± 2.55 | 79.55 ± 3.36 | *** |
| Years of formal Education (y) | 5.02 ± 3.90 | 5.34 ± 4.09 | 4.44 ± 3.61 | *** |
| Lifestyle (%) | | | | |
| Exercising | 58.67 | 60.51 | 55.42 | * |
| Smoking | 24.12 | 26.25 | 20.35 | ** |
| Drinking | 24.28 | 27.55 | 18.50 | *** |
| No. of diseases | 2.16 ± 1.54 | 2.08 ± 1.68 | 2.30 ± 1.35 | ** |
| ADL score (mean ± std) | 0.39 ± 1.66 | 0.23 ± 1.38 | 0.68 ± 1.92 | *** |
| SPMSQ score (mean ± std) | 9.07 ± 1.47 | 9.30 ± 1.35 | 8.68 ± 1.55 | *** |
| MNA score | 26.01 ± 2.70 | 26.29 ± 2.78 | 25.52 ± 2.55 | *** |

Std, Standard deviation; ADL, Activity of Daily Living; SPMSQ, Short Portable Mental Status Questionnaire; MNA, Mini-Nutritional Assessment.
*Values for old adults aged 65–74 and ≥ 75 years were significantly different each other on basis of Chi-square test or Student's t-test. * $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.
[a] Study participants were ≥ 65 years old and had SPMSQ score at 1999 > 2 points.
[b] Values were weighting-adjusted according to sampling design.

## 3. Results

Table 1 shows the characteristics of the study participants in 1999. The participants' average age was 73 years and they had an average of two diseases. Their average ADL, SPMSQ, and MNA scores in 1999 were 0.39, 9.07, and 26.01, respectively. The proportion of those who smoked, drank alcohol, and exercised were 24.12%, 24.28% and 58.67%, respectively. The participants in the 65–74 years-old age group had a significantly higher educational level, higher proportions of smokers, alcohol drinkers, and exercisers, and higher SPMSQ and MNA scores than those in the ≥75-years-old age group. Participants in the ≥75 years-old age group had significantly more diseases and higher ADL scores than those in the 65–74 years-old age group.

Table 2 presents the results of the multivariate linear regression analysis of the associations of changes in exercising and smoking over 4- and 8-year periods, and the MNA scores with subsequent 4- and 8-year SPMSQ scores. For all participants, current and consistent exercise were positively associated with subsequent 4-year SPMSQ scores (β (95%CI) = 0.55 (0.27–0.83) and 0.55 (0.32–0.78), $P =$ 0.0001 and < 0.0001, respectively). The MNA score was positively correlated with the subsequent 4- and 8-year SPMSQ scores (β (95%CI) = 0.04 (0.01–0.08) and 0.06 (0.01–0.11), $P =$ 0.0185 and 0.0119, respectively).

After adjusting for confounding variables, current and consistent exercise were positively associated with subsequent 4-year SPMSQ scores for both the 65–74 and ≥ 75 years-old age groups (For the 65–74 years-old age group: β (95%CI) = 0.53 (0.21–0.85) and 0.40 (0.14–0.67), $P =$ 0.0010 and 0.0025, respectively; for the ≥ 75 years-old age group: β (95%CI) = 0.53 (0.01–1.06) and 0.82 (0.40–1.25), $P =$ 0.0470 and 0.0002, respectively). Past exercise was negatively associated with the subsequent 8-year SPMSQ score for the ≥ 75 years-old age group (β (95%CI) = −0.97 (−1.76 to −0.17), $P = 0.0175$). The MNA score was positively correlated with the subsequent 4- and 8-year SPMSQ scores for the 65–74 years-old age group (β (95%CI) = 0.05 (0.00–0.09) and 0.07 (0.01–0.12), $P = 0.0350$ and 0.0146, respectively). Smoking and alcohol consumption habits were not correlated with the subsequent 4- and 8-year SPMSQ scores for either age group.

Table 3 presents the results of the multivariate logistic regression analysis of the associations of changes in exercising and smoking, and the MNA scores over 4- and 8-year periods, with cognitive decline over the 4- and 8-year periods. For all participants, current, consistent exercise, and MNA score were negatively associated with cognitive decline over 4 years (aOR (95% CI) = 0.51 (0.33–0.77), 0.55 (0.40–0.77), and 0.95 (0.91–1.00), $P =$ 0.0016, 0.0004, and 0.0435, respectively). Past exercise was positively associated with cognitive decline over 8 years (aOR (95% CI) = 1.67 (1.06–2.63), $P = 0.0260$).

For the adults aged 65–74 years, current and consistent exercise were negatively associated with cognitive decline over 4 years (aOR (95% CI) = 0.47 (0.26–0.87) and 0.56 (0.35–0.88), $P = 0.0154$ and 0.0131, respectively). The MNA score was negatively associated with cognitive decline over 4 and 8 years (aOR (95% CI) = 0.90 (0.84–0.97) and 0.92 (0.86–1.00), $P = 0.0061$ and 0.0405, respectively).

Among the older adults aged ≥75 years, consistent exercise was negatively associated with cognitive decline over 4 years (aOR (95% CI) = 0.55 (0.34–0.88), $P = 0.0121$), whereas consistent smoking was positively associated cognitive decline (aOR (95% CI) = 1.99 (1.12–3.56), $P = 0.0198$). Past exercise was positively associated with cognitive decline over 8 years (aOR (95% CI) = 2.91 (1.31–6.45), $P = 0.0085$). Alcohol consumption was not associated with cognitive decline over 4 or 8 years in either age group.

## 4. Discussion

### 4.1. Exercise

This study found that adults ≥ 65 years-old with current and consistent exercise habits had better cognitive performance over subsequent 4-year periods, as evaluated by the SPMSQ, than the adults in the same age group without current and consistent exercise habits. The adults aged 65–74 years, who were current and consistent exercisers had a reduced likelihood of cognitive decline of 53% and 44% over 4 years compared to those who were not exercisers. Among the older adults aged ≥ 75 years, consistent exercise reduced the likelihoods of cognitive decline by 45% over 4 years compared to those who did not exercise. Furthermore, the adults who exercised in the past but did not continue to exercise had a significant increase (3-fold likelihood) in cognitive decline over 8 years, especially among the adults ≥ 75 years old.

Previous studies have demonstrated the protective effects of physical exercise on cognitive decline (Bosma et al., 2002; Fratiglioni, Paillard-Borg, & Winblad, 2004; Ottenbacher et al., 2014). Individuals who engage in more activities have been reported to have significantly less cognitive decline compared to those who do not engage in activities (Bosma et al., 2002; Fratiglioni et al., 2004). Community-dwelling Chinese adults aged 60 years and over with regular physical exercise habits (> 5 years) had better performance on cognitive tests than did those with no exercise habits (Lam et al., 2009).

Physical exercise has many benefits for physical and mental health and it may enhance cognitive reserve (Cheng, 2016; Cooper et al., 2014; Holstila et al., 2017; Lam et al., 2009; Loprinzi, 2016). By analyzing five cohort studies, Cooper et al. (2014) observed that high levels of physical capability were associated with high subsequent levels of wellbeing in old adults. Therefore, it demonstrated the importance of maintaining physical capability in adults' later life. The potential mechanisms underlying the protective effects of physical exercise on cognitive function might be multidimensional. Physical exercise provides neuroprotection and has metabolic effects that counter oxidative stress, inflammation, and aging of the brain (Deary et al., 2009; Fleckenstein et al., 2015; García-Mesa et al., 2016).

Our results are consistent with those of previous studies. Moreover, the positive effects of consistency of exercise on cognitive performance, cognitive reserve, and protection from decline were explored in this study. We found that consistent exercise is beneficial to subsequent cognitive performance, especially among ≥ 75 year-old adults, and that it has a protective effect against cognitive decline. However, having past exercise experience, but not continuing one's exercise habits might lead to a loss of cognitive reserve and an increased risk of cognitive

**Table 2**
Multivariate linear regression analysis of the associations[a] of changes of exercising and smoking over 4- and 8-years periods and MNA score with subsequent 4- and 8-year SPMSQ scores[b].

| | 2003 | | | | | | 2007 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All (n = 1770) | | 65-74 (n = 1109) | | ≥ 75 (n = 661) | | All (n = 1125) | | 65-74 (n = 785) | | ≥ 75 (n = 340) | |
| | β (95%CI) | *P* | β (95%CI) | *P* | β (95%CI) | *P* | β (95%CI) | *P* | β (95%CI) | *P* | β (95%CI) | *P* |
| Exercising | | | | | | | | | | | | |
| Not an exerciser | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past exercisers | −0.05 (−0.34 to 0.23) | 0.7092 | 0.13 (−0.20 to 0.47) | 0.4393 | −0.29 (−0.79 to 0.21) | 0.2612 | −0.30 (−0.69 to 0.08) | 0.1245 | 0.06 (−0.37 to 0.49) | 0.7809 | −0.97 (−1.76 to −0.17) | 0.0175* |
| Current exercisers | 0.55 (0.27 to 0.83) | 0.0001*** | 0.53 (0.21 to 0.85) | 0.0010** | 0.53 (0.01 to 1.06) | 0.0470* | −0.05 (−0.41 to 0.31) | 0.7910 | 0.001 (−0.39 to 0.39) | 0.9944 | −0.17 (−0.95 to 0.61) | 0.6727 |
| Consistent exercisers | 0.55 (0.32 to 0.78) | < 0.0001*** | 0.40 (0.14 to 0.67) | 0.0025** | 0.82 (0.40 to 1.25) | 0.0002*** | 0.22 (−0.07 to 0.52) | 0.1393 | 0.21 (−0.10 to 0.53) | 0.1886 | 0.28 (−0.37 to 0.94) | 0.3914 |
| Smoking | | | | | | | | | | | | |
| Not a smoker | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past smokers | −0.09 (−0.43 to 0.25) | 0.5937 | −0.02 (−0.40 to 0.35) | 0.9005 | −0.17 (−0.85 to 0.51) | 0.6263 | 0.10 (−0.34 to 0.53) | 0.6701 | −0.07 (−0.53 to 0.40) | 0.7776 | 0.68 (−0.33 to 1.69) | 0.1875 |
| Current smokers | 0.22 (−0.38 to 0.82) | 0.4690 | 0.08 (−0.56 to 0.73) | 0.8026 | 0.68 (−0.57 to 1.93) | 0.2858 | −0.10 (−0.84 to 0.63) | 0.7807 | 0.19 (−0.57 to 0.95) | 0.6236 | −0.89 (−2.77 to 0.99) | 0.3537 |
| Consistent smokers | 0.07 (−0.18 to 0.32) | 0.5753 | 0.19 (−0.08 to 0.47) | 0.1690 | −0.11 (−0.62 to 0.40) | 0.6833 | 0.02 (−0.31 to 0.36) | 0.8897 | 0.005 (−0.34 to 0.35) | 0.9786 | 0.03 (−0.81 to 0.88) | 0.9351 |
| Alcohol drinking | | | | | | | | | | | | |
| Not a drinker | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past drinkers | 0.08 (−0.21 to 0.37) | 0.6067 | 0.16 (−0.17 to 0.49) | 0.3485 | −0.04 (−0.57 to 0.50) | 0.8968 | −0.01 (−0.37 to 0.35) | 0.9619 | 0.17 (−0.23 to 0.58) | 0.3991 | −0.11 (−0.85 to 0.62) | 0.7613 |
| Current drinkers | −0.10 (−0.43 to 0.23) | 0.5592 | −0.16 (−0.53 to 0.20) | 0.3844 | 0.06 (−0.59 to 0.71) | 0.8589 | −0.11 (−0.50 to 0.28) | 0.5761 | −0.15 (−0.57 to 0.27) | 0.4908 | −0.04 (−0.88 to 0.80) | 0.9237 |
| Consistent drinkers | −0.09 (−0.35 to 0.17) | 0.5004 | −0.14 (−0.42 to 0.14) | 0.3377 | 0.10 (−0.46 to 0.65) | 0.7349 | −0.15 (−0.46 to 0.17) | 0.3701 | −0.28 (−0.62 to 0.05) | 0.0995 | 0.43 (−0.32 to 1.19) | 0.2613 |
| MNA score | 0.04 (0.01 to 0.08) | 0.0185* | 0.05 (0.00 to 0.09) | 0.0350* | 0.04 (−0.02 to 0.10) | 0.2210 | 0.06 (0.01 to 0.11) | 0.0119* | 0.07 (0.01 to 0.12) | 0.0146* | 0.05 (−0.04 to 0.14) | 0.2998 |
| Intercept | 12.65 | < 0.0001*** | 11.66 | < 0.0001*** | 14.67 | < 0.0001*** | 11.75 | < 0.0001*** | 9.20 | < 0.0001*** | 16.60 | < 0.0001*** |

ADL, Activity of Daily Living; SPMSQ, Short Portable Mental Status Questionnaire; MNA, Mini-Nutritional Assessment.
* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.
[a] Adjusted for gender, age, years of formal education, ADL score at 1999, and the number of diseases.
[b] Subjects with SPMSQ score at 1999 ≤ 2 points were excluded.

**Table 3**
Multivariate logistic regression analysis of the associations[a] of changes of exercising and smoking over 4- and 8-years periods and MNA score with cognitive decline[b] over 4- and 8-years periods.

| | 1999-2003 | | | | | | 1999–2007 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | All (n = 1770) | | 65–74 (n = 1109) | | ≥ 75 (n = 661) | | All (n = 1155) | | 65–74 (n = 807) | | ≥ 75 (n = 348) | |
| | OR (95%CI) | *P* | OR (95%CI) | *P* | OR (95%CI) | *P* | OR (95%CI) | *P* | OR (95%CI) | *P* | OR (95%CI) | *P* |
| Exercising | | | | | | | | | | | | |
| Not an exerciser | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past exercisers | 1.12 (0.76–1.63) | 0.5719 | 0.99 (0.56–1.74) | 0.9766 | 1.22 (0.72–2.07) | 0.4584 | 1.67 (1.06–2.63) | 0.0260* | 1.15 (0.64–2.06) | 0.6388 | 2.91 (1.31–6.45) | 0.0085** |
| Current exercisers | 0.51 (0.33–0.77) | 0.0016** | 0.47 (0.26–0.87) | 0.0154* | 0.55 (0.31–1.00) | 0.0505 | 0.88 (0.55–1.39) | 0.5698 | 0.81 (0.46–1.43) | 0.4584 | 1.07 (0.47–2.43) | 0.8802 |
| Consistent exercisers | 0.55 (0.40–0.77) | 0.0004*** | 0.56 (0.35–0.88) | 0.0131* | 0.55 (0.34–0.88) | 0.0121* | 0.77 (0.52–1.14) | 0.1915 | 0.76 (0.48–1.21) | 0.2458 | 0.81 (0.39–1.67) | 0.5632 |
| Smoking | | | | | | | | | | | | |
| Not a smoker | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past smokers | 1.23 (0.71–2.15) | 0.4643 | 1.45 (0.70–3.00) | 0.3155 | 0.91 (0.38–2.19) | 0.8379 | 0.91 (0.53–1.57) | 0.7302 | 1.07 (0.54–2.12) | 0.8503 | 0.72 (0.28–1.87) | 0.5009 |
| Current smokers | 0.50 (0.14–1.72) | 0.2692 | 0.69 (0.15–3.09) | 0.6233 | 0.29 (0.04–2.42) | 0.2523 | 0.89 (0.27–2.93) | 0.8506 | 0.85 (0.17–4.19) | 0.8383 | 0.84 (0.14–5.16) | 0.8503 |
| Consistent smokers | 1.33 (0.89–2.01) | 0.1668 | 0.85 (0.46–1.56) | 0.5996 | 1.99 (1.12–3.56) | 0.0198* | 1.31 (0.81–2.12) | 0.2721 | 1.34 (0.75–2.39) | 0.3240 | 1.50 (0.56–3.97) | 0.4185 |
| Alcohol drinking | | | | | | | | | | | | |
| Not a drinker | Reference | | Reference | | Reference | | Reference | | Reference | | Reference | |
| Past drinkers | 0.87 (0.54–1.42) | 0.5855 | 0.71 (0.31–1.65) | 0.4274 | 1.05 (0.56–1.99) | 0.8708 | 0.99 (0.63–1.57) | 0.9783 | 1.16 (0.66–2.03) | 0.6129 | 0.75 (0.34–1.66) | 0.4723 |
| Current drinkers | 1.34 (0.79–2.25) | 0.2740 | 1.00 (0.44–2.25) | 0.9937 | 1.74 (0.84–3.59) | 0.1352 | 0.80 (0.45–1.42) | 0.4490 | 0.82 (0.40–1.67) | 0.5855 | 0.74 (0.27–2.06) | 0.5657 |
| Consistent drinkers | 1.04 (0.66–1.65) | 0.8529 | 1.67 (0.93–3.02) | 0.0889 | 0.55 (0.26–1.19) | 0.1289 | 0.75 (0.46–1.23) | 0.2564 | 0.74 (0.40–1.38) | 0.3445 | 0.78 (0.33–1.81) | 0.5578 |
| MNA score | 0.95 (0.91–1.00) | 0.0435* | 0.90 (0.84–0.97) | 0.0061** | 1.00 (0.93–1.07) | 0.9310 | 0.95 (0.89–1.00) | 0.0597 | 0.92 (0.86–1.00) | 0.0405* | 0.97 (0.88–1.07) | 0.5452 |

OR (95%CI), Odd ratio (95% confidence interval); ADL, Activity of Daily Living; SPMSQ, Short Portable Mental Status Questionnaire; MNA, Mini-Nutritional Assessment.
* $P < 0.05$, ** $P < 0.01$, and *** $P < 0.001$.
[a] Adjusted for gender, age, years of formal education, ADL score at 1999, and the number of diseases.
[b] SPMSQ score at 1999 > 2 points and SPMSQ score decreased ≥ 2 points over 4 and 8 years.

decline.

### 4.2. Nutrition

Our results indicate that MNA scores were significantly associated with the subsequent 4- and 8-year SPMSQ scores for 65–74-year-old adults. The younger group of older adults (65–74 years old) in this study with low baseline MNA scores had a significant increase (by 10 and 8%) in the likelihood of cognitive decline over 4 and 8 years, respectively. Low MNA scores reflect poor nutritional status in older adults and can be used to predict the likelihood of cognitive decline; thus, good nutritional status should enhance cognitive reserve. MNA scores have been reported to be correlated with cognitive performance, and poor nutritional status has been associated with a higher rate of cognitive decline (Dumont et al., 2005; Guerin et al., 2005; Malara et al., 2014). A 6-month follow-up study showed a strong correlation between cognitive deterioration and worsening of nutritional status in residents living in a long-term-care facility in Italy (Malara et al., 2014). Oxidative stress and inflammation, which are associated with obesity, metabolic syndrome, and insulin resistance, have been proposed as mechanisms to explain the influence of nutritional factors on cognitive health (Dominguez & Barbagallo, 2017). Poor nutrition might be a fundamental determinant of cognitive frailty. Taken together, our study found that MNA scores predicted the likelihood of cognitive decline, and low MNA scores were associated with an increase in subsequent cognitive decline, especially among the adults in the 65–74-years-old age group.

### 4.3. Smoking

This study's adults ≥ 75-year-old, who smoked consistently, had a significant (two-fold) increase in the risk of cognitive decline over 4 years compared to the non-smokers. Our results showed effects of chronic smoking on cognitive decline. Cigarette smoking has been reported to be associated with cognitive impairment in other studies (Hagger-Johnson et al., 2013; Zhou et al., 2003). Zhou et al. (2003) revealed that current smokers had a significantly higher risk of cognitive impairment than those who had never smoked. Cigarette smoking has been reported to increase inflammation, thrombosis, and oxidative stress, and as a result, it is strongly associated with cardiovascular damage and it is related to cognitive impairment.

### 4.4. Limitation

Several limitations should be taken into account when interpreting the study's results. Information on lifestyle, such as dietary and nutritional factors, exercise, and smoking, were obtained through self-report questionnaires; the study lacked objective measurements. "Exercise" was defined by participants as a low-intensity activity, such as walking; thus, it was included in the exercise activities. The intensity of exercise was not objectively measured. Objective measures of physical capability may be useful predictors of subsequent health outcomes in community-dwelling old populations (Cooper et al., 2011). Dietary and nutritional data were collected only in 1999; therefore, this information was unavailable in the follow-up surveys. Thus, changes in nutritional status during the study period and their influence on cognitive function were not examined. We excluded participants with cognitive test scores that were low or missing. As low cognitive scores were associated with both missing data and dropouts, selection bias might have been introduced.

We compared the characteristics of participants who were followed-up and not followed-up. The participants who were lost to follow-up were older and more males, had significantly worst baseline functional ability of daily life, cognitive function, and nutritional status, and had more diseases than those who were followed-up in the survey wave. Old age, males, high ADL score, low SPMSQ score, low MNA score and high

number of diseases may be the predictors of loss to follow-up.

Participants with the greatest cognitive decline might have been those who were unable to continue to exercise and had poor nutritional status. Therefore, the associations between lifestyle and nutritional status and cognitive functions might be bi-directional; therefore, the potential for reverse-causal relationships cannot be ruled out.

## 5. Conclusions

In conclusions, exercise, smoking, and nutritional status were associated with cognitive function in adults aged 65 years and over. Current and consistent exercise had beneficial effects on the cognitive function and reserve of adults aged ≥ 65 years, and significantly reduced the occurrence of subsequent 4-year cognitive decline. Previous exercise experience without continued exercise habits increased the likelihood of cognitive decline in the subsequent 8-year period, especially for adults aged ≥ 75 years. Nutritional status evaluated by the MNA predicted the likelihood of subsequent cognitive decline. Poor nutritional status increased subsequent 4- and 8-year cognitive decline among adults aged 65–74 years. Consistent smokers aged ≥ 75years had a significantly higher risk of cognitive decline over 4 years. Therefore, current and consistent exercise and good nutrition should benefit cognitive function and cognitive reserve, and protect against cognitive decline among older adults, whereas discontinued exercise, poor nutritional status, and cigarette smoking might be harmful to cognition and increase the risk of cognitive decline.

## Conflict of interest

The authors declare that they do not have any conflicts of interest.

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