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Mediating role of frailty/pre-frailty on the association between exercise participation and traffic crashes among Japanese community-dwelling older drivers

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Abstract

Background Driving is essential for maintaining independence. This study aimed to assess the mediating role of frailty status in the association between exercise participation and traffic crashes among Japanese community-dwelling older drivers.

Methods This 2-year longitudinal study included data of 3,934 Japanese community-dwelling older drivers aged ≥ 65 years in Kasama City who did not require long-term care and participated in a postal survey in 2019 and 2021 at baseline and follow-up, respectively. The participants who exercised at least one–three times per month at baseline were classified as exercisers. Frailty status was assessed using the seven-domain Kihon Checklist. A self-reported history of traffic crashes was collected during the follow-up survey. The effect of exercise participation on traffic crash involvement was analyzed using logistic regression after adjusting for covariates. Mediation analyses were performed to determine the mediating effects of frailty status.

Results A total of 357 (23.7%) and 1,147 (76.3%) older drivers were classified as exercisers and non-exercisers, respectively. Logistic regression analyses showed that exercise participation significantly reduced the risk of traffic crash involvement at follow-up (odds ratio [OR] = 0.586; 95% confidence interval [CI], 0.359–0.956) and was significantly associated with a lower risk of frailty/pre-frailty (OR = 0.479; 95% CI, 0.372–0.617). Although there was no significant association between exercise participation and traffic crash involvement at follow-up (OR = 0.631; 95% CI, 0.384–1.037), frailty/pre-frailty was associated with a significantly higher risk of traffic crash involvement compared with robustness (OR = 1.649; 95% CI, 1.061–2.563). The Sobel test revealed that frailty/pre-frailty mediated the association between exercise participation and traffic crash involvement at follow-up (p = .01). Additionally, among the seven domains of the Kihon Checklist, the physical domain mediated the association between exercise participation and traffic crash involvement at follow-up (p = .01).

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Conclusions Exercise participation could significantly lower the risk of traffic crashes, with frailty/pre-frailty acting as a mediating factor. Our findings indicated that managing frailty is crucial for both public health and crash prevention, emphasizing the need for promoting these measures among older drivers.

Clinical trial number
Not applicable.

Keywords Frailty status, Exercise participation, Traffic crash, Older driver

Background

Driving is a crucial mode of transportation for older adults, particularly in rural areas, as it supports their independence [1]. To ensure safe driving, older drivers need to maintain strong driving skills. Among the various driving-related abilities, certain aspects—such as visual function; motor and physical factors; cognitive performance; mental health; and social factors—are open to enhancement [2]. However, some attributes may be less adaptable, resembling specific neurological disorders. Of late, the effect of exercise involvement on those modifiable skills has gained significant attention. Exercise interventions have been shown to improve driving performance by enhancing various safety-related abilities, including movement speed, visual attention, and lower limb mobility [3, 4]. Therefore, engaging in regular exercise may be vital not only for maintaining high levels of physical and cognitive function, reducing depression, and improving social interactions [5–7] but also for ensuring safe driving and sustaining independent living.

Frailty, a geriatric syndrome characterized by age-related declines in physiological reserve and function, represents overall health conditions and accumulated deficits [8, 9]. It is a potential pathway through which exercise may influence driving ability. According to previous studies, frailty is associated with poorer physical function [10], cognitive impairment [11], and self-reported vision impairment [12], all of which correlate with driving-related ability. Additionally, both frailty and pre-frailty are significantly associated with self-reported traffic crashes compared with non-frailty [13, 14]. Therefore, preventing frailty through exercise participation seems to be a crucial factor for maintaining safe driving behavior.

However, there have been no prospective observational studies that evaluated the association between exercise participation and traffic crashes or explored the mediating role of frailty status. Therefore, further longitudinal studies should be conducted to determine the mechanisms through which exercise participation could reduce the risk of future traffic crashes among older drivers. The potential mediating role of frailty status can be explored through mediation analysis. Statistical mediation analysis allows us to understand how an independent variable (X) affects a dependent variable (Y) through the indirect effect of a mediation variable (M) [15]. Accordingly, mediation analysis could identify whether frailty status (M) mediates the effects of exercise participation (X) on the risk of future traffic crashes (Y) in this study. Understanding these pathways may help design exercise programs that optimize crash prevention in older drivers, with an emphasis on frailty prevention. However, there is limited evidence of the existence of these pathways. We hypothesized that exercise participation might decrease the risk of future traffic crashes through the mediation of frailty status in older drivers.

In view of the above, this study aimed to investigate the effects of exercise participation on the risk of future traffic crashes among older drivers in a 2-year longitudinal study. Additionally, we aimed to elucidate the mediating effect of frailty status to provide evidence for crash prevention strategies based on the epidemiology of older drivers in rural Japan.

Methods

Study design and participants

This was a 2-year prospective cohort study among community-dwelling older adults conducted in Kasama City (population, 74,481; area, 240.4 km^2; the proportion of older adults, 31.6% in 2019). Kasama City is a typical rural area in Japan, as it is famous for primary industries with forest and farmland covering > 60% of the total area. It is also well-known for various activities and services promoted and conducted for health care [16]. A list of 24,000 older adults aged 65–85 years who had never accessed long-term care insurance (LTCI) services was obtained from the basic resident register. Regarding our survey, we randomly chose one-third of these individuals, amounting to 8,000 participants. In November 2019, a self-administered questionnaire was mailed to all selected participants. A total of 3,934 older adults participated in the baseline survey after completing the consent form and questionnaire and mailing them back in prepaid envelopes to the study coordinating center (response rate, 49.2%). In October 2021, a follow-up survey with the same content was conducted among these 3,934 older adults. A total of 383 older adults who moved out of the city or received LTCI services during the follow-up period were excluded. Responses were received from 2,703 older adults (response rate, 76.1%). Of these,

we excluded 1,199 older adults who were not included in the baseline analysis and completed incomplete questionnaires at the follow-up survey. Ultimately, 1,504 participants were included in the final analysis. A flowchart of the study is shown in Fig. 1.

All participants were informed of the study details in writing and their voluntary return to the questionnaire was considered consent to participate in this study. This study was approved by the Ethics Committee of the University of Tsukuba (Ref. Tai 019–101).

Measurements

Exercise participation

Questions about exercise participation included "Do you exercise on your own?" and "Do you exercise with others?" to which participants were instructed to respond with "rarely," "one to three times a month," "once a week," "two to three times a week," or "four or more times a week." Exercise participation was classified as "non-exerciser" (answered "rarely" for both questions), and the latter answers were classified as "exerciser" [17].

Frailty status measured using the Kihon checklist

A simple self-reporting yes/no questionnaire, the Kihon Checklist (KCL) (See Supplementary Table 1), consisting of 25 questions, was used to measure frailty status. The KCL was divided into seven domains, such as instrumental activities of daily living (IADL) domain (five questions), physical domain (five questions), nutrition domain (two questions), oral domain (three questions), socialization domain (two questions), memory domain (three questions), and mood domain (five questions). Each participant was instructed to answer "negative" (score, 1) or "positive" (score, 0), for a total possible score of 25. The cutoff points for each domain were adopted from a previous systematic review [18]; and scores below the cutoff points indicated a low- or at-risk status in that domain. The categories of frailty were established using the method proposed by Satake et al. [19], with the following score ranges: frailty (8–25 points), pre-frailty (4–7 points), and robust (0–3 points). To increase statistical power and delineate progression from robustness to frailty more sharply, we combined the frailty and pre-frailty groups into a single category, termed "frailty/pre-frailty", for the purpose of comparative analysis with the robust category.

Driving habits

Older drivers were defined as those who drove at least once a week on average in the past year. Therefore, older

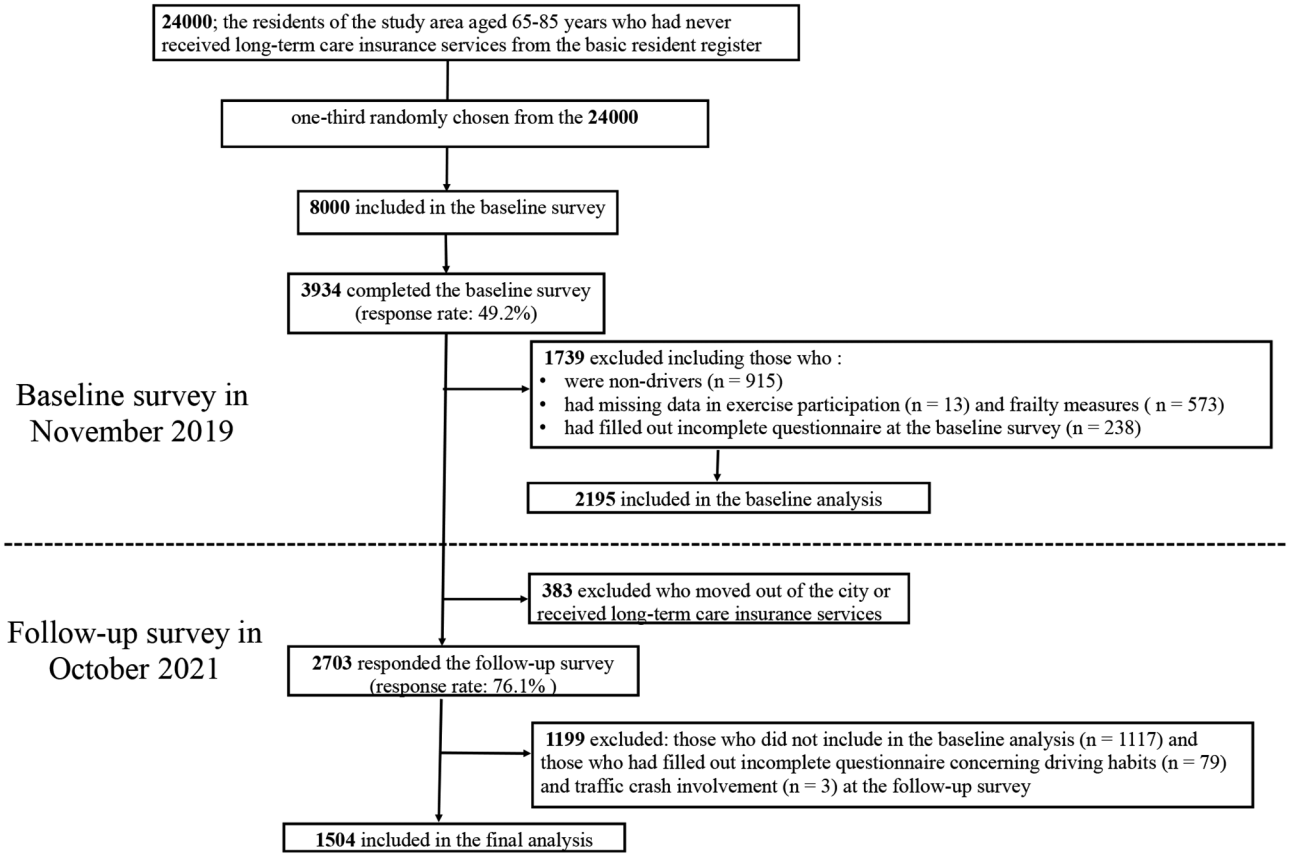

Fig. 1 Flow chart of this study

adults who had returned their driving license, did not drive currently, engaged in infrequent driving (driving less than once a week), or had unknown contact details were classified as non-drivers and excluded from the study. The number of self-reported days in an average week (0–7) formed the driving frequency measure. Driving distances in the past year were classified as follows: ≤ 4999, 5000–10,000, and ≥ 10,000 km/year.

Traffic crash involvement and near-miss traffic incident

Traffic crash involvement was assessed using a self-reported yes/no question: "Have you been involved in a traffic crash in the past year when you were the driver?" Considering those who had been involved in traffic crashes, we further asked about the details of the crashes (multiple answers allowed): (1) crash occurred when the vehicle collided with a pedestrian; (2) crash occurred when the vehicle collided with a stationary obstruction, such as a tree, pole, or building that led to property damage; and (3) crash occurred when the vehicle collided with another vehicle.

Near-miss traffic incidents were assessed using a self-reported yes/no question: "Have you been involved in a near-miss traffic incident in the past year when you were the driver?".

Covariates

We selected covariates as potential confounders a priori, including age, sex, years of education, economic status, living alone, smoking, alcohol consumption, clinical history of hip pain, history of traffic crash involvement, and history of near-miss traffic incidents. Specifically, age, sex, years of education, economic status, history of traffic crash involvement, and history of near-miss traffic incidents may differ in terms of physical activity levels, frailty-related functional abilities (such as cognitive health, depression, and social health), or the risk of traffic crash involvement or unsafe driving behaviors [20].

Economic status was assessed using the question, "How do you feel about your current economic situation?" Respondents could rate their feelings on a scale ranging from "Very difficult," "Slightly difficult," "Normal," "Somewhat rich," to "Very rich." For analytical purposes, we operationally defined the categories "Very difficult" and "Slightly difficult" as representing "Poor" economic status. Economic status is a crucial determinant that influences an individual's capacity to participate in physical activities [21] and their likelihood of being involved in traffic crashes. It impacts access to resources such as exercise facilities, healthcare services, and safe transportation options. Moreover, the existing research indicates that older adults who live alone face a higher risk of depression [22, 23] and experience more pronounced cognitive decline compared with those who live with others [24, 25]. Excessive alcohol consumption among older adults has been linked to accelerated cognitive decline [26], while tobacco use contributes significantly to medical disabilities and mortality rates within the older adult population than abuse of all other substances combined [27]. Musculoskeletal pain, including hip pain, diminishes the quality of life; impairs physical, social, and psychological well-being; and is correlated with high levels of physical activity [28]. All these factors potentially impact driving-related abilities.

Conditions for mediation

Baron and Kenny (1986) [15] outline the conditions under which a variable can act as a mediator in a causal pathway. Considering a variable to be a mediator, regression analyses must demonstrate statistically significant relationships at the initial three stages, as follows: First, independent variable must significantly predict the dependent variable (X → Y). Second, independent variable must significantly predict the mediator (X → M), where the mediator is treated as the dependent variable in relation to the independent variable. Third, the mediator must significantly predict the dependent variable when the effect of the independent variable is controlled for (M → Y), functioning as the independent variable with respect to the dependent variable. These three steps should collectively indicate a direct effect. If any of these relationships fail to be statistically significant, mediation cannot be inferred and is deemed unlikely or unattainable. Upon establishing statistical significance in these steps, the analysis can move to the fourth step. Fourth, the impact of the mediator on the relationship between X and Y is then assessed to determine whether a full or partial mediation model is present. A full mediation model is indicated when X no longer significantly influences Y after controlling for M; in other words, the relationship between X and Y diminishes to the point of insignificance. On the other hand, if the influence of X on Y remains significant but is diminished, a partial mediation model is supported [29].

Statistical analyses

We allocated the participants into two groups according to exercise participation: non-exercise and exercise. Mediation analyses followed by Baron and Kenny's causal steps method [15] were used to explore the association among exercise participation, frailty status, and traffic crash involvement at follow-up. The following conditions were used in this study: (1) logistic regression analyses were used to assess the association between exercise participation and traffic crash involvement at follow-up; (2) the association between exercise participation and frailty/pre-frailty; and (3) logistic regression analyses that simultaneously included exercise participation and

frailty/pre-frailty as dependent variables and traffic crash involvement at follow-up as dependent variables (direct effect) were used to determine whether frailty/pre-frailty influenced the association between exercise participation and traffic crash involvement at follow-up. Age, sex, years of education, economic status, living alone, smoking, alcohol consumption, clinical history of hip pain were the covariates adjusted using these three analyses. In addition to the above covariates, when analyzing condition (1) and (3), history of traffic crash involvement and history of near-miss traffic incidents at baseline were also included. The results are presented as odds ratios (ORs) with 95% confidence intervals (CIs). All above analyses were performed using SPSS version 27.0 (SPSS, Tokyo, Japan), and statistical significance was set at $p<.05$. Finally, the Sobel test was conducted using an interactive calculation tool for mediation tests (http://quantpsy.org/sobel/sobel.htm) to examine indirect effects, and frailty/pre-frailty was considered a mediator when there was a significant indirect effect.

Results

Characteristics of the participants across exercise participation

Among the 1504 participants, 357 (23.7%) and 1147 (76.3%) were classified as exercisers and non-exercisers, respectively. The characteristics of demographic variables, years of education, living alone, economic status, smoking, alcohol consumption, clinical history, frailty measures, driving habits, near-miss traffic incidents, and traffic crash involvement across exercise participation are presented in Table 1.

Mediation analysis

During the follow-up period, 91 (6.1%) older drivers were involved in traffic crashes. Figure 2 summarizes the results of the mediation analysis of exercise, frailty/pre-frailty, and traffic crash involvement at follow-up. There was a significant total effect of exercise participation on traffic crash involvement (OR = 0.586; 95% CI, 0.359–0.956) and a significant association between exercise participation and frailty/pre-frailty (OR = 0.479; 95% CI, 0.372–0.617). Although analysis of direct effects showed no significant association between exercise participation and traffic crash involvement at follow-up (OR = 0.631; 95% CI, 0.384–1.037), frailty/pre-frailty was significantly associated with traffic crash involvement at follow-up (OR = 1.649; 95% CI, 1.061–2.563). The Sobel test for indirect effects was statistically significant ($p=.01$). In conclusion, the results indicated that frailty/pre-frailty could mediate the association between exercise participation and traffic crash involvement at follow-up.

Mediation analysis was used to identify which KCL domain mediated the association between exercise participation and traffic crash involvement at follow-up. Among the seven KCL domains, the results showed that only lower physical function (the physical domain) mediated this association. The Sobel test for indirect effects was statistically significant ($p=.01$) (Fig. 3).

Discussion

This study used a 2-year longitudinal design to confirm that exercise participation has a preventive effect on traffic crash involvement. We hypothesized that frailty could likely mediate the association between exercise participation and traffic crash involvement at follow-up as a mediating factor. As expected, based on Baron and Kenny's causal steps method, the results in this study showed that when frailty/pre-frailty was introduced as a mediator in the analysis, exercise participation decreased their effect on traffic crashes at follow-up, suggesting the full mediation of frailty/pre-frailty. Furthermore, the Sobel test showed a significant difference in the mediating effect. This finding suggests that frailty/pre-frailty prevention may be more important compared with exercise participation in decreasing the risk of traffic crashes among community-dwelling older Japanese drivers.

To the best of our knowledge, this is the first study that investigated the effect of exercise participation on future traffic crashes and identified a significant total effect of exercise participation on traffic crash involvement, indicating that exercisers had a lower risk of traffic crashes compared with non-exercisers. Most previous studies on the association between physical activity or exercise and driving outcomes have primarily focused on the effects of exercise interventions on driving performance and various safety-related abilities among older drivers [3, 4]. Only one cross-sectional study from the USA ($n=2,990$) has explored the relationship between physical activity levels and motor vehicle crashes and showed that neither vigorous nor moderate physical activity was significantly associated with self-reported crashes in the previous year [20]. Different exposure to physical activity level versus exercise participation may influence the final results. Moreover, variations between cross-sectional and longitudinal studies, and in target populations, should be considered.

As hypothesized, our findings revealed that frailty/pre-frailty completely mediated the association between exercise participation and traffic crash involvement at follow-up. This implies that encouraging exercise among older drivers might reduce the risk of future traffic crashes by preventing frailty/pre-frailty. The total KCL score utilized to evaluate frailty status is extensively used in Japan to identify older adults at risk of needing support or care. This score demonstrates a strong correlation with frailty phenotypes introduced by Fried et al. [8], which were derived from the Cardiovascular Health

Table 1 Participants' characteristics across exercise participation

		Non-exerciser (n = 357)	Exerciser (n = 1147)
		Mean ± SD	Mean ± SD
Demographic variables			
Age		71.2 ± 4.7	71.5 ± 4.5
Female	% (n)	36.7 (131)	42.8 (491)
Body mass index	(kg/m^2)	23.4 ± 3.4	23.1 ± 2.7
Years of education	% (n)		
≤ 9		14.0 (50)	9.8 (112)
10–12		57.4 (205)	56.4 (647)
≥ 13		28.6 (102)	33.8 (388)
Living alone	% (n)	10.1 (36)	10.1 (116)
Economic status (poor)	% (n)	24.1 (86)	14.5 (166)
Smoking	% (n)	17.4 (62)	6.4 (73)
Alcohol consumption	% (n)	50.7 (181)	56.6 (649)
Clinical history	% (n)		
Stroke		3.1 (11)	2.4 (28)
Hypertension		44.8 (160)	42.8 (491)
Diabetes		14.0 (50)	13.3 (152)
Osteoporosis		2.8 (10)	4.2 (48)
Heart disease		14.8 (53)	12.0 (138)
Low back pain		28.3 (101)	26.9 (309)
Hip pain		4.5 (16)	2.3 (26)
Knee pain		13.4 (48)	13.0 (149)
Frailty measures (total KCL frailty)	% (n)		
Robust		50.7 (181)	69.6 (798)
Pre-frailty		37.5 (134)	24.4 (280)
Frailty		11.8 (42)	6.0 (69)
Driving habits			
Driving frequency	(d/w)	5.6 ± 1.8	5.5 ± 1.7
Driving distances (km/year)	% (n)		
≤ 4999		40.3 (144)	36.5 (419)
5000–10000		37.0 (132)	43.9 (504)
≥ 10000		22.7 (81)	19.5 (224)
Near-miss traffic incidents	% (n)	7.3 (26)	13.0 (149)
Traffic Crash Involvement	% (n)	7.0 (25)	9.2 (105)
Near-miss traffic incidents at follow-up	% (n)	9.8 (35)	12.0 (128)
Traffic Crash Involvement at follow-up	% (n)	7.8 (28)	5.5 (63)

Data are the mean ± standard deviation or % (n)

Abbreviation: KCL: Kihon Checklist

Study frailty index—a benchmark considered highly reliable on a global scale [19]. Our decision to integrate both frail and pre-frail states in our current investigation stems from the recognition that individuals in either condition could potentially derive benefits from interventions designed to enhance their health and mitigate the likelihood of further deterioration. Additionally, incorporating both groups allows for a larger sample size, thereby enhancing the statistical capacity to discern distinctions or connections with the outcomes under examination. In 2019, Japan's Ministry of Health, Labour and Welfare recommended using a frailty screening questionnaire to replace the standard questionnaire for specific health checkups in older adults [30]. Currently, frailty prevention measures are highly valued in Japan and implemented across local communities [31]. Therefore, our findings could provide additional evidence of the benefits of frailty screening and exercise-based prevention from the perspective of driving safety. Additionally, further mediation analysis identified that among the seven domains of the KCL, lower physical function (physical domain) specifically mediated the relationship between exercise participation and traffic crash involvement at follow-up. However, for the domains of IADL, nutrition, oral, socialization, memory, and mood, these significance criteria were not met in Step 2 (i.e., the effect of X on M;

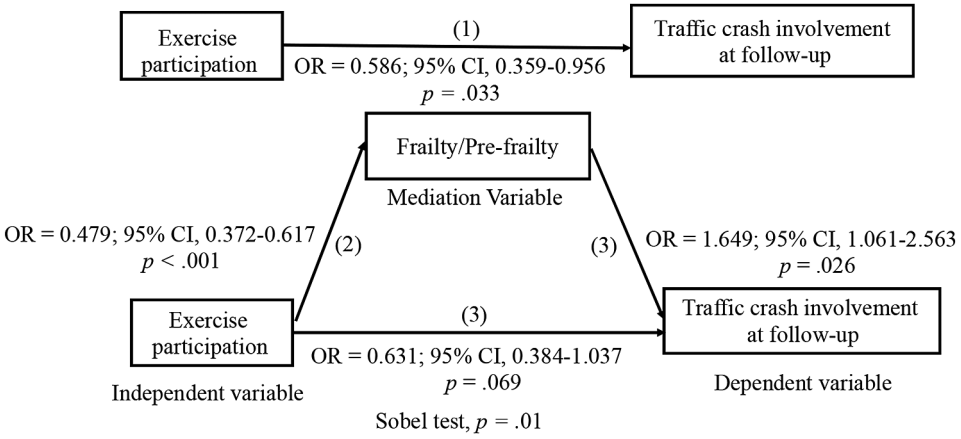

Fig. 2 Mediation model of exercise participation, frailty/pre-frailty, and traffic crash involvement at follow-up. The model is adjusted for age, sex, years of education, economic status, living alone, smoking, alcohol consumption, clinical history of hip pain using these three analyses. In addition to the above covariates, when analyzing condition (1) and (3), history of traffic crash involvement and history of near-miss traffic incidents at baseline are also included

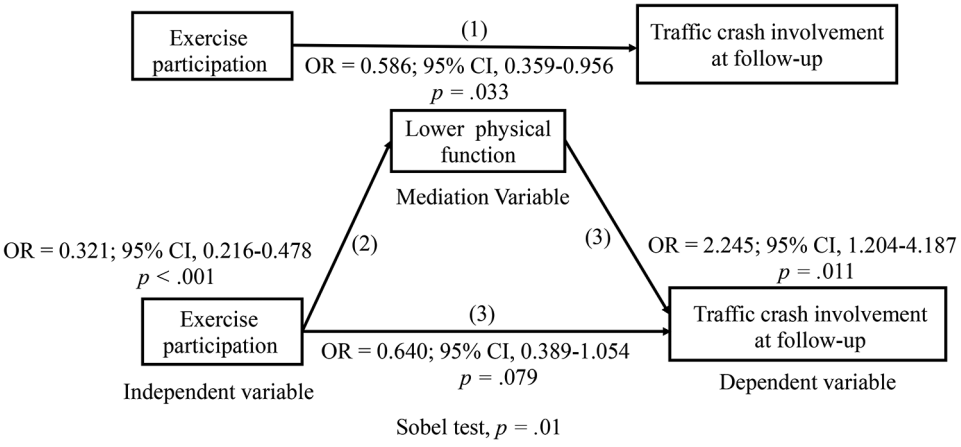

Fig. 3 Mediation model of exercise participation, lower physical function, and traffic crash involvements at follow-up. The model is adjusted for age, sex, years of education, economic status, living alone, smoking, alcohol consumption, clinical history of hip pain using these three analyses. In addition to the above covariates, when analyzing condition (1) and (3), history of traffic crash involvement and history of near-miss traffic incidents at baseline are also included

see Supplementary Table 2) or Step 3 (i.e., the effect of M on Y; see Supplementary Table 3), thereby preventing further mediation analysis for these domains. Previous study has demonstrated moderate associations between the KCL physical domain and several typical physical function variables, including gait speed, the Short Physical Performance Battery, the five-repetition chair stand test, and timed up-and-go scores [32]. Given that some measures are associated with increased traffic crash rates [33], the KCL physical domain emerges as a key mediator in reducing traffic crashes through exercise participation. Previous studies have demonstrated that poor cognitive function, including general cognitive function and specific domains, such as attention and memory, was linked to a higher risk of traffic crashes [34–36]. Similarly, our prior work also showed a link between cognitive impairment and traffic crashes [37]. Notably, despite this established connection, there were no significant differences observed between the KCL memory domain and traffic crash involvement at follow-up in the present study (see Supplementary Table 4). The potential explanation about this discrepancy could lie in the different study designs. Both studies used the same population; however, the present longitudinal study assessed participants at both baseline and follow-up, unlike our previous cross-sectional study, which relied exclusively on baseline data. This methodological difference might have influenced the observed relationships. It is worth mentioning that another study has reported that the KCL memory domain can predict incident dementia over a 5.7-year study period [38]. Thus, whether a longer follow-up period would affect the relationship between the KCL memory domain and future traffic crash involvement warrants further investigation in future studies. Furthermore, in terms of the KCL memory domain (See Supplementary Table 5), participants reported the following

issues: memory loss observed by others (6.6%), looking up phone numbers to call (8.1%), and difficulty recalling today's date (17.3%), which were lower than those reported in a previous study (20.8%, 5.8%, and 20.3%, respectively) [39]. Therefore, the higher cognitive function of our participants might have contributed to their lower risk of traffic crash involvement.

The strength of this 2-year longitudinal study is its large sample size because the survey was sent to one-third of older citizens who live in Kasama City by targeting individuals at home, as well as those who underwent health checkups. Despite the inherent risk of various types of participation bias, our study design incorporated random sampling to diminish the probability of our sample disproportionately favoring any specific subgroup within the population. Additionally, we utilized multiple recruitment strategies to ensure a balanced representation, thereby reducing the likelihood of overrepresentation among individuals who are more inclined to utilize health services. However, this study has some limitations that warrant mention. First, this study used self-administered questions to investigate exercise participation, which may have introduced measurement bias. Self-reported exercise frequency can be influenced by over- or underestimation issues. Participants might exaggerate their exercise habits due to social desirability concerns or recall biases. Such discrepancies could lead to misclassification, such as categorizing individuals as "exercisers" when they engage in physical activity less frequently than reported. As a result, the observed correlation between exercise participation and traffic crash involvements might have been either underestimated or overstated. In addition, during the period of our study, the coronavirus disease 2019 pandemic posed significant challenges that could have potentially impacted the reliability and generalizability of our findings. Specifically, the unique circumstances associated with the pandemic, including widespread lockdowns, social distancing measures, and disruptions to daily routines, likely influenced participants' exercise habits [40]. Therefore, future studies in exercise habits or physical activity monitoring should focus on using objective accelerometer data during non-pandemic periods. Second, this study did not assess the type, duration, or intensity of exercise. Several interventional studies have shown that exercise can prevent or attenuate frailty as a single component or as part of a multicomponent intervention. Most of these studies have used resistance or aerobic training combined with resistance and/or balance training, and the exercise intensity was low to moderate [41]. Furthermore, future studies should investigate varying levels of exercise frequency and intensity to assess the existence of a dose-response relationship with the risk of traffic crashes, which was not feasible in the present study due to sample size limitations. Third, this study focused on older drivers living in Kasama City, Ibaraki Prefecture. In Japan, older adults predominantly rely on driving as their main mode of transportation, a phenomenon particularly notable in rural areas where public transportation is considered inadequate [42]. The previous study from the 2017 Kasama Health Checkup for Longevity survey indicated that the proportion of current older drivers in Kasama City is as high as 80.5% [1]. Additionally, the aging rate in this area is 31.6%, slightly exceeding the national average of 28.9% [43]. Consequently, the study's outcomes could be influenced by the distinct characteristics of the study location and the daily routines of its inhabitants. Thus, to widen the scope of research, examining other areas within Japan is essential. Fourth, our dataset does not provide comprehensive information on whether participants' LTCI status was a result of functional impairments caused by traffic crashes. Similarly, we did not differentiate whether the participants were at fault in traffic crashes they were involved in the past year. The assumption that all reported incidents reflect driver error or health-related factors could result in an overestimation of crash risk. Additionally, this study did not explore the details of vehicle features, such as the comparison between manual and automatic transmissions or the presence of advanced safety systems. However, a meta-analysis by Fildes et al. [44] revealed that real-world driving scenarios showed a 38% reduction in rear-end collisions for vehicles equipped with low-speed Automatic Emergency Braking compared to those without this technology. In line with this, Japan's transport ministry has required new domestic vehicles to be equipped with automatic braking systems from November 2021 [45]. Consequently, future studies should strive to collect more detailed survey data on injury specifics, fault attribution, and vehicle characteristics. Finally, because the assessment of exercise participation and frailty statuses was only conducted at baseline, longitudinal studies are necessary for clarifying the association between exercise participation and frailty statuses among older drivers. Additionally, future long-term follow-up studies should consider the overall changes in exercise participation and frailty statuses during the follow-up period.

Conclusions

This 2-year longitudinal study found that Japanese community-dwelling older drivers who engaged in regular exercise had a significantly lower risk of future traffic crashes compared with those who did not exercise. Additionally, frailty/pre-frailty, particularly in the domain of lower physical function, significantly mediated the association between exercise participation and future traffic crashes. Our findings can help inform frailty-related policies and interventions aimed to enhance safe

driving among older adults to ensure a vibrant, super-aged society.

Abbreviations

KCL	Kihon Checklist
IADL	Instrumental Activities of Daily Living
OR	Odds Ratio
CI	Confidence Interval
LTCI	Long-term Care Insurance

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05998-3.

Supplementary Material 1

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Author contributions
JL: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. YF: Methodology, Investigation, Formal analysis, Data curation, Writing - review & editing. KF: Methodology, Investigation, Writing - review & editing. JS: Methodology, Writing - review & editing. KN: Investigation, Writing - review & editing. TO: Supervision, Writing - review & editing.

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Data availability
The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the guidelines of the Declaration of Helsinki. All participants were informed of the study details in writing and their voluntary return to the questionnaire was considered consent to participate in this study. This study was approved by the Ethics Committee of the University of Tsukuba (Ref. Tai 019–101).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Abe T, Seol J, Kim M, Okura T. The relationship of car driving and bicycle riding on physical activity and social participation in Japanese rural areas. J Transp Health. 2018;10:315–21.
2. Anstey KJ, Wood J, Lord S, Walker JG. Cognitive, sensory and physical factors enabling driving safety in older adults. Clin Psychol Rev. 2005;25:45–65.
3. Marmeleira JF, Godinho MB, Fernandes OM. The effects of an exercise program on several abilities associated with driving performance in older adults. Accid Anal Prev. 2009;41:90–7.
4. Marottoli RA, Allore H, Araujo KLB, Iannone LP, Acampora D, Gottschalk M, et al. A randomized trial of a physical conditioning program to enhance the driving performance of older persons. J Gen Intern Med. 2007;22:590–7.
5. Kishimoto H, Ohara T, Hata J, Ninomiya T, Yoshida D, Mukai N, et al. The long-term association between physical activity and risk of dementia in the community: the Hisayama study. Eur J Epidemiol. 2016;31:267–74.
6. Pasco JA, Williams LJ, Jacka FN, Henry MJ, Coulson CE, Brennan SL, et al. Habitual physical activity and the risk for depressive and anxiety disorders among older men and women. Int Psychogeriatr. 2011;23:292–8.
7. Santanasto AJ, Glynn NW, Lovato LC, Blair SN, Fielding RA, Gill TM, et al. Effect of physical activity versus health education on physical function, grip strength and mobility. J Am Geriatr Soc. 2017;65:1427–33.
8. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. J Gerontol Biol Sci Med Sci. 2001;56:M146–56.
9. Rockwood K. What would make a definition of frailty successful? Age Ageing. 2005;34:432–4.
10. Sewo Sampaio PY, Sampaio RAC, Coelho Júnior HJ, Teixeira LFM, Tessutti VD, Uchida MC, et al. Differences in lifestyle, physical performance and quality of life between frail and robust Brazilian community-dwelling elderly women. Geriatr Gerontol Int. 2016;16:829–35.
11. Robertson DA, Savva GM, Kenny RA. Frailty and cognitive impairment–a review of the evidence and causal mechanisms. Ageing Res Rev. 2013;12:840–51.
12. Liljas AEM, Carvalho LA, Papachristou E, De Oliveira C, Wannamethee SG, Ramsay SE, et al. Self-reported vision impairment and incident prefrailty and frailty in english community-dwelling older adults: findings from a 4-year follow-up study. J Epidemiol Community Health. 2017;71:1053–8.
13. Doi T, Ishii H, Tsutsumimoto K, Nakakubo S, Kurita S, Shimada H. Car accidents associated with physical frailty and cognitive impairment. Gerontology. 2020;66:624–30.
14. Liu J, Fujii Y, Seol J, Fujii K, Kim M, Tateoka K et al. Frailty phenotype associated with traffic crashes among older drivers: a cross-sectional study in rural Japan. J Transp Health. 2020;18.
15. Baron RM, Kenny DA. The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J Pers Soc Psychol. 1986;51:1173–82.
16. Okura T, Tsuji T, Tsunoda K, Kitano N, Yoon J-Y, Saghazadeh M, et al. Study protocol and overview of the Kasama study: creating a comprehensive, community-based system for preventive nursing care and supporting successful aging. J Phys Fit Sports Med. 2017;6:49–57.
17. Fujii Y, Seol J, Joho K, Liu J, Inoue T, Nagata K, et al. Associations between exercising in a group and physical and cognitive functions in community-dwelling older adults: a cross-sectional study using data from the Kasama study. J Phys Ther Sci. 2021;33:15–21.
18. Sewo Sampaio PY, Sampaio RA, Yamada M, Arai H. Systematic review of the Kihon checklist: is it a reliable assessment of frailty? Geriatr Gerontol Int. 2016;16(8):893–902.

19. Satake S, Senda K, Hong YJ, Miura H, Endo H, Sakurai T, et al. Validity of the Kihon checklist for assessing frailty status. Geriatr Gerontol Int. 2016;16:709–15.
20. Talwar A, Mielenz TJ, Hill LL, Andrews HF, Li G, Molnar LJ, et al. Relationship between physical activity and motor vehicle crashes among older adult drivers. J Prim Care Community Health. 2019;10:2150132719859997.
21. Yang H, An R, Clarke CV, Shen J. Impact of economic growth on physical activity and sedentary behaviors: a systematic review. Public Health. 2023;215:17–26.
22. Fukunaga R, Abe Y, Nakagawa Y, Koyama A, Fujise N, Ikeda M. Living alone is associated with depression among the elderly in a rural community in Japan. Psychogeriatrics. 2012;12:179–85.
23. Kikuchi H, Takamiya T, Odagiri Y, Ohya Y, Nakaya T, Shimomitsu T, et al. Gender differences in association between psychological distress and detailed living arrangements among Japanese older adults, aged 65–74 years. Soc Psychiatry Psychiatr Epidemiol. 2014;49:823–30.
24. Fujii K, Fujii Y, Kitano N, Sato A, Hotta K, Okura T. Mediating role of instrumental activities of daily living ability on cognitive function of older adults living alone: a 4-year longitudinal study from the Kasama study. Medicine. 2021;100:e27416.
25. van Gelder BM, Tijhuis M, Kalmijn S, Giampaoli S, Nissinen A, Kromhout D. Marital status and living situation during a 5-year period are associated with a subsequent 10-year cognitive decline in older men: the FINE study. J Gerontol B Psychol Sci Soc Sci. 2006;61:213–9.
26. Sabia S, Elbaz A, Britton A, Bell S, Dugravot A, Shipley M. Alcohol consumption and cognitive decline in early old age. Neurology. 2014;82:332–9.
27. Jilk TJ, Mumenthaler MS. Substance use disorders in the elderly. Handbook of mental health and aging. INC; 2020:185–210.
28. Niederstrasser NG, Attridge N. Associations between pain and physical activity among older adults. PLoS ONE. 2022;17:e0263356.
29. Abu-Bader S, Jones TV. Statistical mediation analysis using the Sobel test and Hayes SPSS process macro. Int J Quant Qual Res Methods. 2021.
30. Satake S, Arai H. Questionnaire for medical checkup of old-old (QMCOO). Geriatr Gerontol Int. 2020;20:991–2.
31. Kojima M, Satake S, Osawa A, Arai H. Management of frailty under COVID-19 pandemic in Japan. Glob Health Med. 2021;3:196–202.
32. Satake S, Kinoshita K, Matsui Y, Arai H. Physical domain of the Kihon checklist: A possible surrogate for physical function tests. Geriatr Gerontol Int. 2020;20:644–6.
33. Ng LS, Guralnik JM, Man C, DiGuiseppi C, Strogatz D, Eby DW, et al. Association of physical function with driving space and crashes among older adults. Gerontologist. 2020;60:69–79.
34. Ball KK, Roenker DL, Wadley VG, Edwards JD, Roth DL, McGwin G, et al. Can high-risk older drivers be identified through performance-based measures in a department of motor vehicles setting? J Am Geriatr Soc. 2006;54:77–84.
35. Fraade-Blanar LA, Ebel BE, Larson EB, Sears JM, Thompson HJ, Chan KCG, et al. Cognitive decline and older driver crash risk. J Am Geriatr Soc. 2018;66:1075–81.
36. Hu PS, Trumble DA, Foley DJ, Eberhard JW, Wallace RB. Crash risks of older drivers: a panel data analysis. Accid Anal Prev. 1998;30:569–81.
37. Liu J, Fujii Y, Fujii K, Seol J, Kim M, Tateoka K, et al. Pre-frailty associated with traffic crashes in Japanese community-dwelling older drivers. Traffic Inj Prev. 2022;23:73–8.
38. Tomata Y, Sugiyama K, Kaiho Y, Sugawara Y, Hozawa A, Tsuji I. Predictive ability of a simple subjective memory complaints scale for incident dementia: evaluation of Japan's National checklist, the Kihon checklist. Geriatr Gerontol Int. 2017;17:1300–5.
39. Okura M, Ogita M, Yamamoto M, Nakai T, Numata T, Arai H. The relationship of community activities with cognitive impairment and depressive mood independent of mobility disorder in Japanese older adults. Arch Gerontol Geriatr. 2017;70:54–61.
40. Ochi S, So M, Hashimoto S, Hashimoto Y, Sekizawa Y. Impact of the COVID-19 pandemic on exercise habits and overweight status in Japan: A nation-wide panel survey. PLOS Glob Public Health. 2023;3:e0001732.
41. Kehler DS, Theou O. The impact of physical activity and sedentary behaviors on frailty levels. Mech Ageing Dev. 2019;180:29–41.
42. Ministry of Land, Infrastructure and Transport of Japan. 7th Nationwide Person Trip Survey; 2021. (https://www.mlit.go.jp/report/press/toshi07_hh_000206.html). (in Japanese).
43. Cabinet, Office. Government of Japan. Annual report on the ageing society 2022. (https://www8.cao.go.jp/kourei/english/annualreport/2022/pdf/2022.pdf).
44. Fildes B, Keall M, Bos N, Lie A, Page Y, Pastor C, et al. Effectiveness of low speed autonomous emergency braking in real-world rear-end crashes. Accid Anal Prev. 2015;81:24–9.
45. Ministry of Land. Infrastructure, Transport and Tourism. https://www.mlit.go.jp/report/press/jidosha08_hh_003618.html. Accessed 31 January 2020 (in Japanese).

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