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Longitudinal association of social participation with locomotive syndrome among Japanese older adults: A 5-year community-based study

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Abstract

Background: Locomotive syndrome (LS), characterized by reduced mobility due to musculoskeletal impairment, is a major contributor to disability and long-term care dependency in aging populations. While structured exercise interventions have demonstrated benefits, the longitudinal impact of real-world social participation on LS remains unclear.

Methods: This community-based prospective cohort study utilized municipal health data from 6,898 adults age ≥65 years in Hamamatsu, Japan who were followed from 2019 to 2024. LS was assessed using the 5-item Geriatric Locomotive Function Scale (GLFS-5). Characteristics of social participation, including frequency, group size, and the type of activity, were recorded. Generalized linear mixed-effects models (GLMMs) with a logit link were used to examine associations between social participation and LS over time, adjusting for age and sex. Missing data were handled using multiple imputation.

Results: At the baseline, 20.4% of participants had LS. Being older and female were significantly associated with higher odds of LS ($p < 0.001$). More frequent participation in social activities (≥2 times/month) and participation in larger groups (≥60 members) were associated with lower odds of LS. However, participation in tea party activities and dementia prevention programs was associated with higher odds of LS. These findings may reflect reverse causality, whereby individuals with poorer baseline physical function preferentially engage in less physically demanding activities.

Conclusions: Characteristics of social participation are longitudinally associated with LS among older adults. These findings highlight the importance of considering the type of activity and participation patterns when designing community-based interventions for healthy aging.

1. Introduction

Population aging is accelerating worldwide (1), posing significant challenges to healthcare systems and long-term care. Japan has the world's most rapidly aging population, with the highest proportion of older adults (2), making the maintenance of functional independence a major public health priority. Concurrently, the number of individuals requiring support or long-term care has steadily increased. According to the 2022 Comprehensive Survey of Living Conditions by the Ministry of Health, Labor, and Welfare of Japan (3), musculoskeletal disorders—including falls, fractures, and joint diseases—are among the leading reasons for needing long-term care and represent the primary reason for requiring support. Locomotive syndrome (LS) (4), first proposed by the Japanese Orthopaedic Association (JOA) in 2007, refers to a condition characterized by reduced mobility due to impairments in the musculoskeletal system. LS has been increasingly recognized as a major contributor to functional decline in aging populations. Epidemiological studies suggest that a substantial proportion of middle-aged and older adults are at risk of LS, with prevalence estimates exceeding 60% in some populations (5). Importantly, LS is a progressive condition involving a decline in muscle strength, balance, and mobility, which are key determinants of independence in daily living. These functional impairments substantially increase the risk of adverse outcomes, including falls, fractures, disability, and subsequent

dependence on long-term care (6, 7). Recent longitudinal studies have further highlighted the close association between LS and other geriatric conditions, such as frailty and sarcopenia, and LS may serve as an early indicator of broader functional decline trajectories in older adults (8). Consequently, early identification and prevention of LS have become critical components of healthy aging strategies in rapidly aging populations.

Recent longitudinal studies have increasingly examined behavioral and lifestyle factors associated with LS, providing important insights into its progression over time. As an example, community-based research in Japan has shown that a higher frequency of participation in long-term care prevention programs is associated with more favorable LS-related outcomes, particularly among men (9). In addition, mounting evidence indicates that lifestyle factors, such as habitual physical activity and exercise behaviors, play a critical role in the onset and progression of LS (10, 11). Despite these findings, however, existing research has largely focused on structured health programs or individual lifestyle behaviors. The potential role of diverse, real-world social participation—and particularly non-exercise social activities—has yet to be sufficiently explored. Moreover, limited evidence is available on how specific characteristics of social participation, such as frequency, group size, and the type of activity, may influence the development and progression of LS differently. Addressing this gap is important, as the progression of LS contributes substantially to increasing demands on healthcare and long-term care systems. Notably, previous studies have suggested that LS is at least partially reversible and can be alleviated through appropriate interventions (12). Therefore, identifying modifiable community-based factors, such as social participation, may provide practical strategies for preventing LS and extending healthy life expectancy in aging populations.

Locomotion training (LT), as proposed by the JOA, consists of simple exercises such as squats and standing on one leg designed to improve lower limb strength and balance (13). A growing body of evidence has demonstrated that LT-based exercise interventions can effectively improve physical function and locomotive ability. Previous intervention studies have reported significant improvements in muscle strength, balance performance, and LS-related indicators following short- to medium-term training programs (14, 15). These findings suggest that targeted exercise interventions help to prevent and alleviate LS. However, most of the existing evidence is derived from settings with structured and supervised interventions, which may not fully reflect real-world conditions for community-dwelling older adults. In daily life, many older individuals are more likely to engage in informal, community-based activities rather than structured exercise programs. Such activities may incorporate both physical and social components, potentially contributing to the maintenance of locomotive function through multiple pathways. Despite this, limited longitudinal evidence is available regarding whether participation in community-based physical and social activities—and particularly those not explicitly designed as exercise interventions—is associated with LS outcomes. This relationship needs to be clarified in order to develop feasible, scalable, and sustainable strategies for LS prevention in aging populations.

Therefore, the primary aim of this study was to examine the longitudinal association between characteristics of social participation and LS among community-dwelling older adults. The secondary

aim was to investigate the differential effects of specific characteristics of social participation, including the type of activity, frequency of participation, and group size, on LS' trajectory. The findings of this study should provide evidence for the development of feasible, scalable, and community-based strategies to prevent locomotive decline and to promote healthy aging in aging populations.

2. Materials and methods

2.1 Survey design

This survey was conducted as part of a community-based preventive care program implemented by the municipal government of the City of Hamamatsu, Japan. The program sought to facilitate healthy aging and prevent functional decline among community-dwelling older adults. Eligible participants were individuals age ≥ 65 years who were living independently and who were not certified as requiring long-term care under the Japanese long-term care insurance system. The program was organized by the local municipality in collaboration with community volunteers and healthcare professionals, and participation was voluntary. Participants participated in group-based activities designed to maintain physical function and prevent LS. These activities included light exercise (e.g., stretching, balance training, and lower-limb strengthening) as well as social activities, such as tea parties, recreational events, and health education sessions. Activities were conducted in local community gathering spaces ("salons") located within walking distance of participants' residences. Sessions were typically held on a regular basis (e.g., once or several times per month) and involved small- to moderate-sized groups. These community-based activities provided opportunities for both social interaction and engagement in health-related behaviors.

2.2 Participants

This study was a community-based prospective cohort using municipal health survey data from community-dwelling older adults in the City of Hamamatsu, Shizuoka Prefecture, Japan. The cohort was established in 2019 as part of a preventive care program, and participants were followed longitudinally. The primary objective was to examine the association between participation in community-based health promotion activities and LS. LS was assessed using the 5-item Geriatric Locomotive Function Scale (GLFS-5). In addition, data on demographic and activity-related variables, including age, sex, group size, years of continuous participation, frequency of participation, and the type of activity, were collected. Eligible participants were individuals age ≥ 65 years who participated in the community-based health program and who completed the required assessments. Participants were excluded if they had severe neurological, orthopedic, or cognitive impairments that could substantially interfere with test performance. All participants provided written informed consent. The study protocol was approved by the Ethics Committee of the Hamamatsu University School of Medicine (Approval No. 25–282). All procedures were conducted in accordance with the Declaration of Helsinki. Participant data were anonymized prior to analysis.

2.3 Questionnaire

Each participant was provided with an on-site recording form on the day of participation. The GLFS-5 was self-administered under the supervision of trained investigators who had received standardized training prior to data collection. Completed questionnaires were collected on-site and checked for completeness immediately after submission. Questionnaires with less than 10% missing data were retained for analysis. Missing values were handled using multiple imputation to reduce potential bias.

2.4 The GLFS-5

The assessment of LS in epidemiological and community-based studies typically relies on validated screening tools, with the most widely used being the Geriatric Locomotive Function Scale (GLFS). The simplified GLFS-5 was developed based on psychometric analyses of the original 25-item scale (GLFS-25) to provide a more practical and efficient screening tool while maintaining adequate validity. Previous studies have demonstrated that the GLFS-5 is highly correlated with the GLFS-25 and that it retains good discriminative ability for identifying individuals at risk of LS (16, 17). Moreover, its applicability has been confirmed in community-dwelling Japanese populations, where it has been widely used in both cross-sectional and longitudinal studies to assess mobility-related functional decline (18). Importantly, GLFS-based measures have also been shown to predict future functional decline and the onset of LS in longitudinal settings, indicating their utility not only as screening tools but also as indicators of disease progression (19). Given its brevity, ease of administration, and established validity, the GLFS-5 is particularly suitable for large-scale community studies and repeated assessments over time. Therefore, the use of GLFS-5 in the current study provides a reliable and feasible approach for evaluating LS in community-dwelling older adults. These items include questions on brisk walking (Q3), climbing stairs (Q12), distance walked distance without rest (Q15), carrying shopping weighing approximately 2 kg (Q17), and performing moderately intense household chores (Q20). In the simplified GLFS-5, a total score of > 6 out of a maximum of 20 points is used to indicate the existence of LS.

2.5 Statistical analysis

Descriptive statistics were used to summarize baseline characteristics of the study population. Continuous variables were assessed for normality using the Shapiro–Wilk test and are expressed as the mean ± standard deviation (SD), as appropriate. Categorical variables are expressed as frequencies and percentages. Participants were classified into two groups according to their GLFS-5 score: a non-locomotive syndrome (non-LS) group (GLFS-5 < 6) and an LS group (GLFS-5 ≥ 6). Baseline differences between groups were assessed using the Mann–Whitney U test for continuous variables and the chi-square test for categorical variables. To examine the longitudinal association between social participation and LS, generalized linear mixed-effects models (GLMMs) with a logit link function were applied. The existence of LS (yes/no) at each time point was treated as the dependent variable. Time (survey wave) and characteristics of social participation (the type of activity, frequency of participation, and group size) were included as fixed effects. A random intercept for each participant was included to account for within-individual correlations due to repeated measurements over time. Multivariable models were adjusted for potential confounders, including age and sex. Additional models further adjusted for activity-related variables as appropriate. Results are reported as odds ratios (ORs) with 95% confidence

intervals (CIs). Missing data were handled using multiple imputation by chained equations assuming they were missing at random. Estimates from imputed datasets were combined using Rubin's rules. All statistical analyses were performed using the software R (version 4.5.0). A two-sided p value < 0.05 was considered statistically significant.

3. Results

3.1 Participant characteristics and single factor analysis

A total of 6,898 community-dwelling older adults were included in the analysis, of whom 1,404 (20.4%) were classified as having LS. The mean age of the participants was 77.8 ± 6.2 years. Participants with LS were significantly older than those without LS (81.9 ± 5.7 vs. 76.8 ± 5.9 years, $p < 0.001$). The prevalence of LS increased progressively with age. In addition, LS was more prevalent among women than men (21.4% vs. 16.8%, $p < 0.001$). In terms of the characteristics of social participation, participants who participated in larger groups and who participated in more frequent activities tended to have a lower prevalence of LS. Differences were also observed across types of activity, with a higher proportion of LS among participants participating in tea parties and dementia prevention programs. Detailed baseline characteristics and results of univariate analyses are shown in Table 1.

Table 1
Baseline characteristics of study participants (n = 6,898)

Variables	All participants	non-LS group	LS group	p-value
	n = 6,898	n = 5,494	n = 1,404	
Age (years, x ± s)	77.83 ± 6.19	76.78 ± 5.88	81.92 ± 5.66	< 0.001*
60 ≤ age < 70 (n, %)	696 (10.1%)	665 (95.5%)	31 (4.5%)	
70 ≤ age < 80 (n, %)	3,413 (49.5%)	3,005 (88.0%)	408 (12.0%)	
80 ≤ age < 90 (n, %)	2,616 (37.9%)	1,752 (67.0%)	864 (33.0%)	
Age ≥ 90 (n, %)	173 (2.5%)	72 (41.6%)	101 (58.4%)	
Sex (n, %)				< 0.001*
Male	1,533 (22.2%)	1,275 (83.2%)	257 (16.8%)	
Female	5,365 (77.8%)	4,218 (78.6%)	1,147 (21.4%)	
Group size (n, %)				< 0.001*
20 less than	809 (11.7%)	675 (83.4%)	134 (16.6%)	
20–40	3,826 (55.5%)	3,043 (79.5%)	783 (20.5%)	
40–60	1,654 (24.0%)	1,261 (76.2%)	393 (23.8%)	
60 or more	609 (8.8%)	515 (84.6%)	94 (15.4%)	
Frequency of physical activity (x ± s)	23.83 ± 12.34	24.45 ± 12.20	21.21 ± 12.56	< 0.001*
Never participated (n, %)	711 (10.3%)	536 (75.4%)	175 (24.6%)	
Participated once a month (n, %)	2,915 (42.3%)	2,208 (75.7%)	707 (24.3%)	
Twice a month (n, %)	1,722 (25.0%)	1,433 (83.2%)	289 (16.8%)	
Three times a month (n, %)	979 (14.1%)	833 (85.1%)	146 (14.9%)	
Four times a month (n, %)	571 (8.3%)	484 (84.8%)	87 (15.2%)	
Type of activity				0.917
Light exercise				
No	1,950 (29.3%)	1,553 (79.6%)	397 (20.4%)	
Yes	4,699 (70.7%)	3,737 (79.5%)	962 (20.5%)	

Note: Data are expressed as the mean ± standard deviation; * indicates statistical significance ($p < 0.05$), “n” indicates the number of participants; non-LS, the non-locomotive syndrome.

Variables	All participants	non-LS group	LS group	p-value
	n = 6,898	n = 5,494	n = 1,404	
Tea party				< 0.001*
No	5,092 (76.6%)	4,167 (81.8%)	925 (18.2%)	
Yes	1,557 (23.4%)	1,123 (72.1%)	434 (27.9%)	
Prevention of dementia				0.1
No	5,169 (77.7%)	4,134 (80.0%)	1,034 (20.0%)	
Yes	1,480 (22.3%)	1,155 (78.0%)	325 (22.0%)	
Fun activities & learning				0.041*
No	3,741 (56.3%)	2,943 (78.7%)	798 (21.3%)	
Yes	2,908 (43.7%)	2,347 (80.7%)	561 (19.3%)	

Note: Data are expressed as the mean ± standard deviation; * indicates statistical significance ($p < 0.05$), “n” indicates the number of participants; non-LS, the non-locomotive syndrome.

3.2 Associations between social participation and LS

The associations between characteristics of social participation and LS were examined using GLMMs with multiple imputation (Table 2, Fig. 8).

Table 2
Association between social activity and locomotive syndrome using generalized linear mixed models

Variables	Groups	Estimate	SE	df	OR	95% CI		p-value
						Lower limit	Upper limit	
Age	60 ≤ age < 70	Reference						
	70 ≤ age < 80	1.355	0.12	205.121	3.879	1.117	1.593	< *0.001**
	80 ≤ age < 90	2.65	0.115	307.863	14.158	2.422	2.878	< *0.001**
	Age ≥ 90	3.746	0.173	279.774	42.378	3.405	4.087	< *0.001**
Sex	Female	Reference						
	Male	-0.335	0.06	194.847	0.715	-0.454	-0.215	< 0.001*
Group size	0–20	Reference						
	20–40	0.064	0.075	671.108	1.066	-0.083	0.212	0.393
	40–60	0.198	0.084	537.357	1.219	0.033	0.363	0.018*
	60 or over	-0.277	0.111	315.091	0.757	-0.497	-0.057	0.013*
Frequency of physical activity	Never participated	Reference						
	Participated once a month	-0.075	0.094	83.157	0.927	-0.262	0.111	0.424
	Twice a month	-0.442	0.098	104.725	0.642	-0.638	-0.247	< 0.001*
	Three times a month	-0.538	0.111	105.921	0.583	-0.758	-0.317	< 0.001*
	Four times a month	-0.508	0.121	135.557	0.601	-0.749	-0.268	< 0.001*

Notes:*Represents statistical significance ($p < 0.05$). SE, standard error; df, degrees of freedom; OR, odds ratio; 95% CI, 95% confidence interval.

Variables	Groups	Estimate	SE	df	OR	95% CI		p-value
						Lower limit	Upper limit	
Number of consecutive years participating in the activity	2019	Reference						
	1 year (2020)	0.067	0.061	117.986	1.070	-0.053	0.189	0.268
	2 years (2021)	0.098	0.054	1.787	1.103	-0.009	0.206	0.074
	3 years (2022)	0.272	0.053	5.057	1.313	0.166	0.378	< 0.001*
	4 years (2023)	0.313	0.058	5.352	1.368	0.197	0.429	< 0.001*
	5 years (2024)	0.353	0.054	6.473	1.424	0.246	0.461	< 0.001*
Type of activity	Light exercise: Yes vs. No	-0.027	0.065	139.997	0.974	-0.155	0.101	0.067
	Tea party: Yes vs. No	0.412	0.066	145.038	1.511	0.281	0.544	< *0.001**
	Prevention of dementia: Yes vs. No	0.184	0.068	140.499	1.202	0.048	0.320	0.008*
	Fun activities & learning: Yes vs. No	0.052	0.066	144.627	1.053	-0.08	0.184	0.437

Notes:*Represents statistical significance (p < 0.05). SE, standard error; df, degrees of freedom; OR, odds ratio; 95% CI, 95% confidence interval.

Age

Age was strongly associated with LS. Compared to participants age 60–69 years, those age 70–79 years had higher odds of LS (OR: 3.879, 95% CI: 1.117–1.593, $p < 0.001$). The odds further increased with age, with ORs of 14.158 for individuals age 80–89 years and 42.378 for those age ≥ 90 years (both $p < 0.001$). Predicted probability curves showed that the probability of LS increased over the follow-up period across all age groups, with a consistently higher probability observed among older participants (Fig. 1).

Sex

Sex was also associated with LS. Male participants had lower odds of LS compared to female participants (OR = 0.715, 95% CI: [-0.454- -0.215], $p < 0.001$). Predicted probability curves indicated an

increase in LS probability over time for both sexes, with a higher probability observed among women throughout the follow-up period (Fig. 2).

Characteristics of social participation

Characteristics of social participation were associated with LS. Compared to participation in groups with fewer than 20 members, participation in groups with40–60 members was associated with higher odds of LS (OR: 1.219, 95% CI: 0.033–0.036, $p = 0.018$), whereas participation in groups of ≥ 60 members was associated with lower odds (OR: 0.757, 95% CI: -0.497- -0.057, $p = 0.013$) (Fig. 3). A higher frequency of participation was associated with lower odds of LS. The odds ratio was 0.642 for participation two times per month, 0.583 for participation three times per month, and 0.601 for participation four times per month ($p < 0.001$ for all). Predicted probability curves showed a decreasing probability of LS with a higher frequency of participation over time.

The number of consecutive years of participation

The number of consecutive years of participation was associated with LS. Compared to the baseline (2019), a longer duration of participation was associated with higher odds of LS, and particularly among those with 3–5 years of follow-up (ORs ranging from 1.313 to 1.424, $p < 0.001$ for all).

Type of activities

In terms of the types of activities, participation in tea parties was associated with higher odds of LS (OR: 1.511, 95% CI: 0.281–0.544, $p < 0.001$), as was participation in dementia prevention activities (OR: 1.202, 95% CI: 0.048–0.32, $p = 0.008$). In contrast, participation in light exercise was not significantly associated with LS after adjustment (OR: 0.974, 95% CI: -0.155- 0.101, $p = 0.067$). In addition, participation in fun activities & learning was not significantly associated with LS after adjustment (OR: 1.053, 95% CI: -0.08-0.184, $p = 0.437$). Predicted probability curves showed a slightly higher probability of LS among participants who participated in tea parties and dementia prevention activities, whereas minimal differences were observed for light exercise and fun activities & learning (Figs. 4–7).

4. Discussion

4.1 Principal findings

This study examined the longitudinal associations between characteristics of social participation and LS among community-dwelling older adults over a five-year follow-up period. Several key findings emerged. First, age was identified as the most prominent factor associated with LS, with a marked increase in risk observed among individuals age ≥ 80 years. Second, a higher likelihood of LS was observed in women compared to men. Third, specific characteristics of social participation, and particularly frequency of participation and group size, were significantly associated with LS. More frequent participation in activities, and especially those involving physical components, was associated with a lower probability

of LS. In addition, heterogeneity was observed across types of activities. Participation in tea parties and dementia prevention activities was associated with higher odds of LS. This pattern may partly reflect underlying differences in baseline functional status or activity intensity. Overall, these findings underscore the multifaceted relationships between aging, social participation, and mobility-related health outcomes, suggesting that both the quantity and quality of social engagement may play important roles in the development and progression of LS.

4.2 Age and LS

In terms of the influence of age, the current study found a clear age-related gradient in the risk of LS, with older individuals exhibiting a consistently higher likelihood of LS over the five-year follow-up period. In particular, the risk increased markedly among those age ≥ 80 years, highlighting the strong influence of advanced age on locomotive decline. This finding is consistent with previous evidence indicating that age-related deterioration in muscle strength, joint flexibility, and balance contributes to progressive impairments in mobility and functional performance among older adults (20, 21). Such physiological declines may lead to reduced walking capacity and increased vulnerability to mobility limitations. Moreover, once functional decline begins, the capacity to maintain or regain physical function may diminish over time, potentially accelerating the progression of LS. These findings underscore the importance of early and proactive prevention strategies. Interventions implemented before the onset of advanced age may be particularly effective in mitigating functional decline. In this context, promoting regular physical activity and sustained social engagement may play a crucial role in preserving musculoskeletal function and delaying the onset or progression of LS in later life.

4.3 Sex differences

In addition to age, sex differences in the risk of LS were also observed. Female participants showed a higher likelihood of developing LS compared to male participants. This finding is consistent with a previous epidemiological study that reported that the prevalence and risk of LS are significantly higher in women than in men among middle-aged and older adults (22). Several biological and social factors may explain this sex disparity. From a physiological perspective, women generally experience a more rapid decline in muscle mass and strength after menopause due to hormonal changes, and particularly reductions in estrogen levels (23). This decline contributes to decreased bone density, reduced muscle strength, and an increased risk of sarcopenia, all of which are closely related to locomotive dysfunction. Moreover, women tend to have a longer life expectancy than men, which increases the cumulative exposure to age-related functional decline. Social and behavioral factors may also contribute to these differences. Older women may experience greater limitations in physical activity or may have a higher prevalence of chronic musculoskeletal conditions such as osteoarthritis. Taken together, these factors may increase the vulnerability of older women to locomotive decline, highlighting the need for targeted preventive strategies for this population.

4.4 Social participation and group characteristics

An important finding of this study is the association between characteristics of social participation and LS. In particular, group size and frequency of participation were significantly related to the probability of LS. Participants who engaged more frequently in physical activity tended to exhibit a lower likelihood of LS during the follow-up period. This finding is consistent with previous research demonstrating that regular physical activity is one of the most effective strategies for preventing mobility decline and maintaining musculoskeletal health in aging populations (24). Regular physical activity can help maintain muscle strength, balancing ability, and joint flexibility, which are essential components of locomotive function. Longitudinal evidence further indicates that maintaining regular exercise habits can significantly decrease the incidence of LS over time (25). Moreover, randomized clinical trials have shown that structured physical activity interventions effectively prevent mobility disability and maintain musculoskeletal function in aging populations (26). Therefore, encouraging older adults to participate in physical activity on a regular basis may represent an important strategy for preventing LS and facilitating healthy aging in community settings. However, a point to note is that the observed associations do not necessarily imply causality. Individuals with better baseline physical function may be more likely to engage in frequent and socially active behaviors, suggesting the possibility of reverse causation.

Interestingly, participation in larger groups (≥ 60 participants) was associated with a lower risk of LS, whereas participation in moderately sized groups (40–60 participants) was associated with a higher risk. This pattern suggests a potential non-linear relationship between group size and LS risk, rather than a simple linear association. One possible explanation relates to differences in group dynamics and social structure. Larger groups may provide greater opportunities for diverse social interactions, stronger social networks, and increased peer support, which may enhance motivation to continue participating and promote sustained engagement in health-related behaviors. Such conditions may facilitate both social connectedness and behavioral reinforcement, which have been shown to contribute to better physical and cognitive health outcomes among older adults. In contrast, moderately sized groups may not fully reap those benefits while also lacking the close interpersonal interactions typically observed in smaller groups. This intermediate group size may represent a transitional structure in which neither strong social cohesion nor extensive network effects are fully established, potentially limiting its positive impact on health behaviors and functional outcomes.

Another possible explanation is selection or composition effects. Larger and more established groups may preferentially attract or retain individuals with better baseline physical function and higher levels of social engagement, whereas moderately sized groups may include a higher proportion of individuals with emerging functional limitations. Such differences in participant characteristics may partly account for the observed non-linear association. Another aspect to consider is that excessively large group sizes may reduce opportunities for individualized interaction. However, in well-organized community settings, larger groups may still engage in structured activities that promote participation and engagement. Taken together, these findings suggest that the relationship between group size and LS is complex and may be influenced by a combination of social network effects, behavioral engagement, and participant selection mechanisms. Group-based activities may provide opportunities for increased social interaction and engagement, which are important components of healthy aging. Previous studies have suggested that

participation in group activities can enhance motivation, promote adherence to regular activities, and foster a supportive social environment among older adults. Group-based exercise programs increase social interaction and significantly improve exercise adherence among community-dwelling older adults (27). In addition, group activities provide opportunities for social connectedness and mutual support, which encourage continued participation and sustained engagement in physical activity (28). Future studies need to further explore these pathways and to determine the optimal group structure for promoting mobility and preventing functional decline among older adults.

4.5 The number of consecutive years of participation

An unexpected finding of this study was that a longer duration of participation was associated with higher odds of LS, and particularly among participants with 3–5 years of follow-up. Although this pattern may initially appear to reflect age-related functional decline, such an explanation is insufficient because age was already adjusted for in the multivariable models. Therefore, one possible explanation is that health status may change over time in ways that are not fully captured by baseline covariates. Previous longitudinal studies in community-dwelling older populations have demonstrated that physical function, comorbidities, and frailty status can deteriorate over relatively short periods. For example, recent cohort studies have reported that approximately 24–35% of older adults experience worsening frailty within 3–4 years of follow-up, even among initially community-dwelling individuals (29, 30). Such changes may increase the risk of mobility limitations and LS over time, independent of chronological age.

In addition, selective participation may partly explain the observed association. Individuals who continue engaging in activities over multiple years may include those who continue to engage in them despite declining physical function, possibly for health maintenance or rehabilitation purposes. In contrast, relatively healthier individuals may discontinue their participation or engage in other activities. Similar patterns have been reported in longitudinal studies of aging, where continued participation in community or health programs often reflects underlying health needs rather than better baseline function. For example, studies have shown that older adults utilizing community-based services or participating in health programs are more likely to have existing health risks or functional limitations, indicating a need-driven pattern of participation rather than a marker of better health status (31, 32). Moreover, previous studies have suggested that social participation is not uniformly beneficial, and its association with health outcomes may depend on participants' baseline functional status and the context of participation. For example, a recent scoping review demonstrated that different types of social participation are associated with distinct health outcomes, rather than consistent benefits across all activities (33). In addition, longitudinal evidence indicates that the health effects of social participation vary according to individual characteristics and participation patterns, highlighting the context-dependent nature of these associations (34). In this context, a longer duration of participation may reflect not only sustained engagement but also underlying vulnerability among participants. Taken together, these findings suggest that the positive association between the duration of participation and LS should be interpreted with caution. Rather than indicating a detrimental effect of long-term participation, it may reflect changes in health status over time and differences in participant

characteristics. Future longitudinal studies incorporating repeated measures of physical function and health status need to be conducted to better clarify these relationships.

4.6 Differences across types of activities

Another important finding of this study is that different types of social activities showed heterogeneous associations with LS among older adults. Participation in tea parties and dementia prevention programs was associated with higher odds of LS. However, these findings should be interpreted with considerable caution, as they are likely influenced by selection bias and reverse causality. Specifically, individuals with poorer baseline physical function or early-stage mobility limitations may be more likely to engage in less physically demanding activities, such as tea parties or cognitively oriented programs, while those with better functional status may preferentially participate in more active or physically engaging activities. This selective participation pattern may lead to an overestimation of the association between certain low-intensity activities and a higher risk of LS. Therefore, the observed positive associations are unlikely to reflect a causal detrimental effect of these activities, but rather underlying differences in baseline health status among participants. In addition, residual confounding cannot be ruled out. Although the current analysis adjusted for age and sex, other important factors—such as baseline physical function, comorbidities, and socioeconomic status—were not fully accounted for and may have influenced both activity selection and risk of LS. Similar methodological concerns have been highlighted in previous epidemiological studies examining the relationship between lifestyle factors and functional decline in older adults.

In contrast, participation in light exercise was not significantly associated with LS after adjustment. This may be partly explained by the relatively low intensity of some community-based exercise programs, which may be insufficient to produce measurable improvements in mobility outcomes. A growing body of evidence suggests that moderate-to-vigorous physical activity is more effective at improving physical function and preventing mobility decline in older populations. For example, randomized controlled trials have demonstrated that structured moderate-intensity physical activity significantly reduces the risk of major mobility disability (26), and higher levels of moderate-to-vigorous activity have been associated with better muscle function and physical performance (35). Taken together, these findings suggest that the observed associations between types of social activities and LS are likely shaped by a combination of selection mechanisms and activity intensity, rather than reflecting direct causal effects. Future studies incorporating more detailed baseline functional assessments and applying causal inference approaches —such as propensity score methods or longitudinal structural modeling—need to be conducted to better disentangle these complex relationships.

This suggests that not all forms of social participation contribute equally to the maintenance of locomotive function. Some activities may provide greater benefits because they involve higher levels of physical movement or more frequent interpersonal interaction. In contrast, activities that primarily involve sedentary participation may provide psychological and social benefits but may have a relatively smaller impact on physical health outcomes. Therefore, the characteristics and intensity of each activity may play an important role in determining its potential health effects. Moreover, different activities may

promote health through multiple pathways. Activities that combine physical movement with social interaction may simultaneously enhance physical fitness, cognitive stimulation, and emotional well-being. Such multidimensional benefits may help older adults maintain functional capacity and resilience to age-related decline. These findings suggest that community programs should not only encourage social participation but also consider the types of activities offered to maximize their potential benefits for maintaining mobility and independence in older adults.

Japan has one of the world's most rapidly aging populations (2), and maintaining mobility and independence among older adults has become a major public health priority. Community-based social participation programs are widely implemented across municipalities as part of preventive care strategies aimed at delaying functional decline and reducing the demand for long-term care. In particular, community "salon" programs and group-based activities provide accessible opportunities for older adults to engage in both physical and social interactions within their local environments. The current findings support the growing recognition that community-based social participation is an important component of healthy aging strategies. Integrating social engagement into preventive health policies may represent a practical and sustainable approach for reducing mobility decline and promoting functional independence in rapidly aging populations.

4.7 Strengths and limitations

This study has several notable strengths. First, it utilized longitudinal data with a five-year follow-up, enabling the assessment of temporal changes in LS and their associations with social participation among older adults. Compared to cross-sectional designs, this longitudinal approach provides stronger evidence for understanding the dynamic relationship between social engagement and functional health outcomes. Second, the use of GLMMs allowed us to account for within-individual correlations arising from repeated measurements and to control for unobserved individual heterogeneity over time, thereby enhancing the robustness of the findings. Third, this study focused on community-dwelling older adults participating in real-world social activities, improving the ecological validity and practical relevance of the results. Importantly, the analysis further considered specific characteristics of social participation—such as group size, frequency of participation, and the type of activity—providing more nuanced evidence to inform community-based prevention strategies.

Despite these strengths, several limitations should be acknowledged. First, a longitudinal design was used, but causal inferences cannot be definitively established. Reverse causality remains possible, as individuals with better baseline physical function may be more likely to engage in social activities. Further longitudinal and interventional studies are warranted to clarify causal pathways and to determine whether specific types or patterns of social participation can effectively prevent or delay the progression of LS. Second, the GLFS-5 checklist was based on self-reported data, which may be subject to recall and reporting bias. Future research should address this limitation by incorporating objective measurements of physical activity and functional performance, such as wearable device data or standardized physical assessments, to improve measurement precision. In addition, the current study did not include detailed clinical information, such as underlying chronic conditions (e.g., musculoskeletal disorders,

cardiovascular diseases, and metabolic diseases), which may act as important confounding factors. Future studies should incorporate comprehensive clinical variables, including comorbidities, to allow for more robust adjustment and a more precise estimation of associations. Third, the study population was derived from a single community, which may limit the generalizability of the findings to other settings or populations with different sociodemographic characteristics. Future studies with more diverse populations and multi-center designs need to be conducted to enhance external validity.

5. Conclusion

In conclusion, the current longitudinal study demonstrated that age and sex were significantly associated with the risk of LS among community-dwelling older adults, with older age groups and women showing a higher likelihood of locomotive decline. Importantly, participation in community-based social activities was associated with a lower probability of LS over the five-year follow-up period. These findings suggest that promoting active social participation may represent a feasible and effective strategy for maintaining physical function and preventing locomotive decline in rapidly aging populations. Future studies should further explore the causal mechanisms underlying this relationship and evaluate intervention programs designed to encourage social engagement among older adults.

Abbreviations

LS: Locomotive syndrome

GLFS-5: 5-item Geriatric Locomotive Function Scale

GLMMs: Generalized linear mixed-effects models

OR: Odds ratio

CI: Confidence interval

JOA: Japanese Orthopaedic Association

SD: Standard deviation

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Ethics Committee of Hamamatsu University School of Medicine (Approval No. 25-282). All participants provided written informed consent prior to participation. All procedures were conducted in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due to privacy and ethical restrictions involving identifiable participant information, but are available from the corresponding author on reasonable request and with permission from the relevant ethics committee.

Competing Interests

The authors declare that they have no competing interests.

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Authors' contributions

Hirano Y: Original draft, Software, Formal analysis, Conceptualization.

Suzuki M, Sato C, Isobe T, Moriguchi T: Review & editing, Validation, Data curation.

Deng Y: Original draft, Methodology, Investigation.

Toshiyuki Ojima, Takashima S, Hasui M: Review & editing, Supervision, Conceptualization.

Yamauchi K: Review & editing, Supervision, Funding acquisition.

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Figures

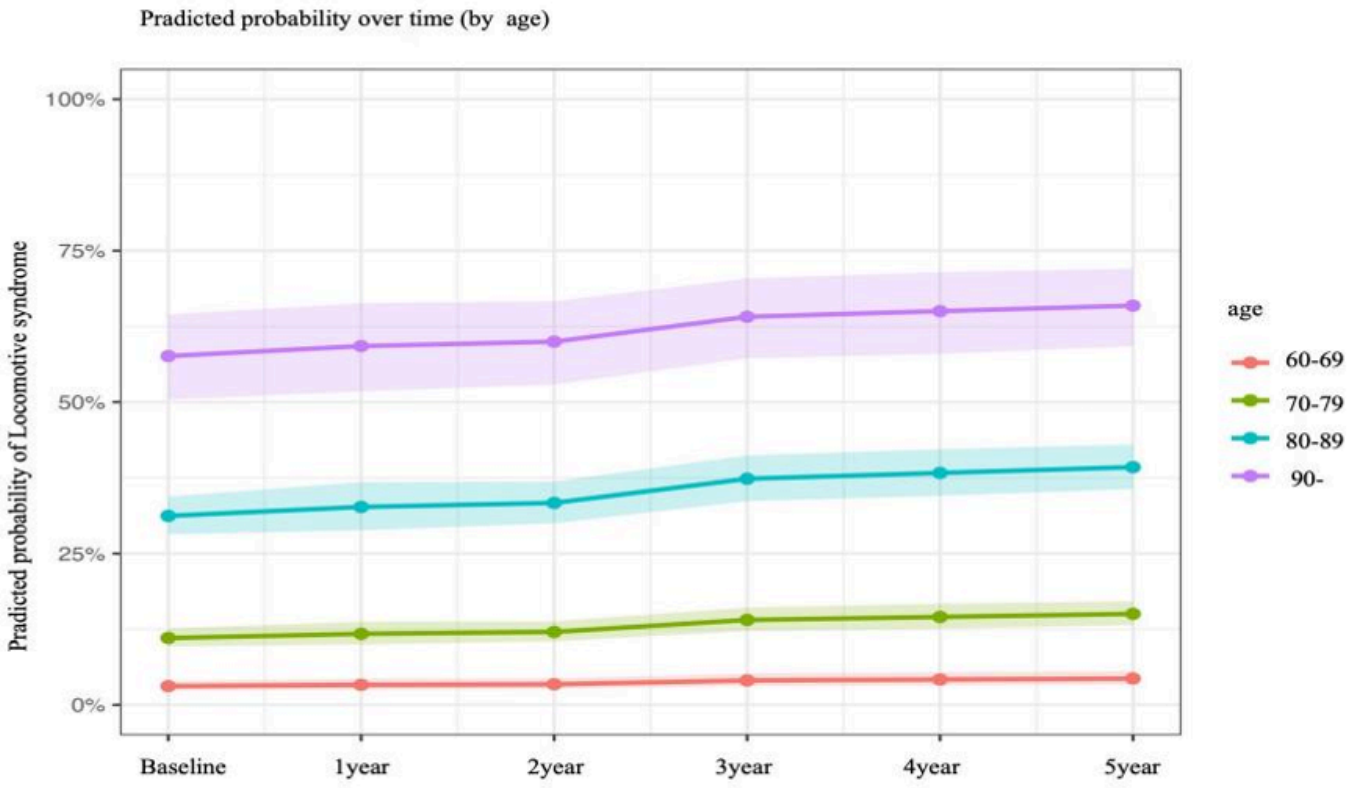


Figure 1. Predicted probability of locomotive syndrome over time according to age group.

Figure 1

See image above for figure legend.

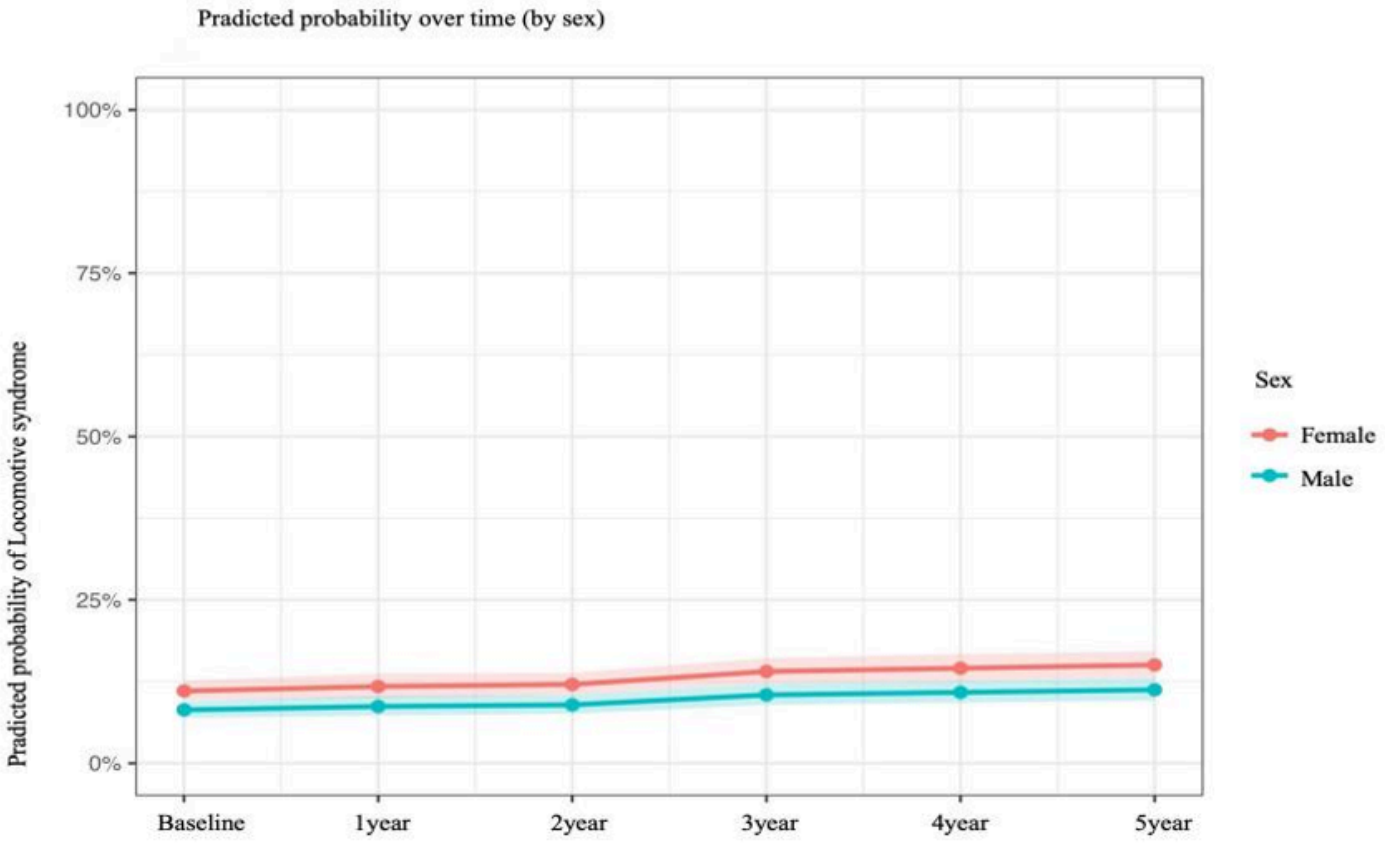


Figure 2. Predicted probability of locomotive syndrome over time stratified by sex.

Figure 2

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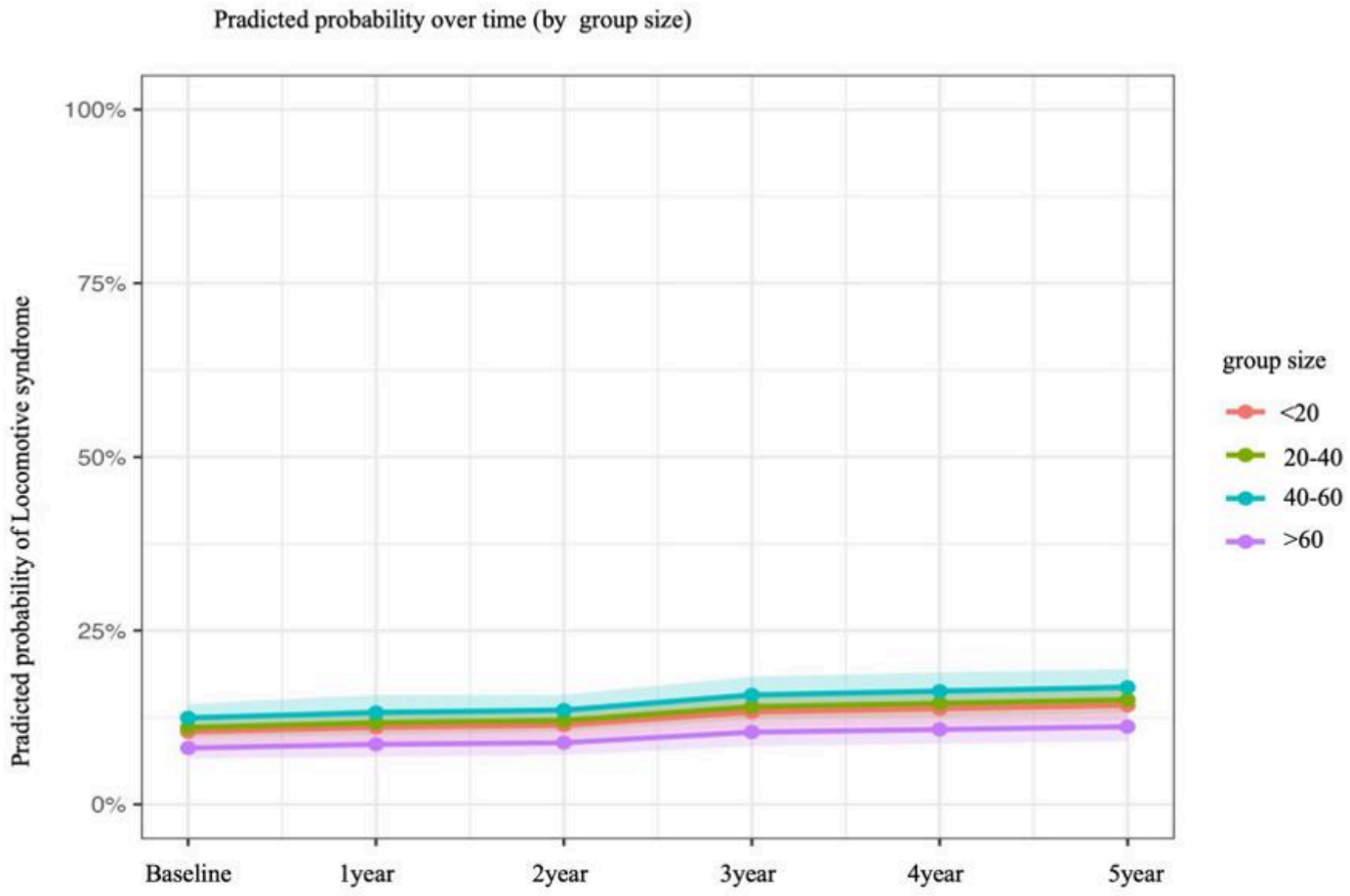


Figure 3. Predicted probability of locomotive syndrome over time according to group size of social participation activities.

Figure 3

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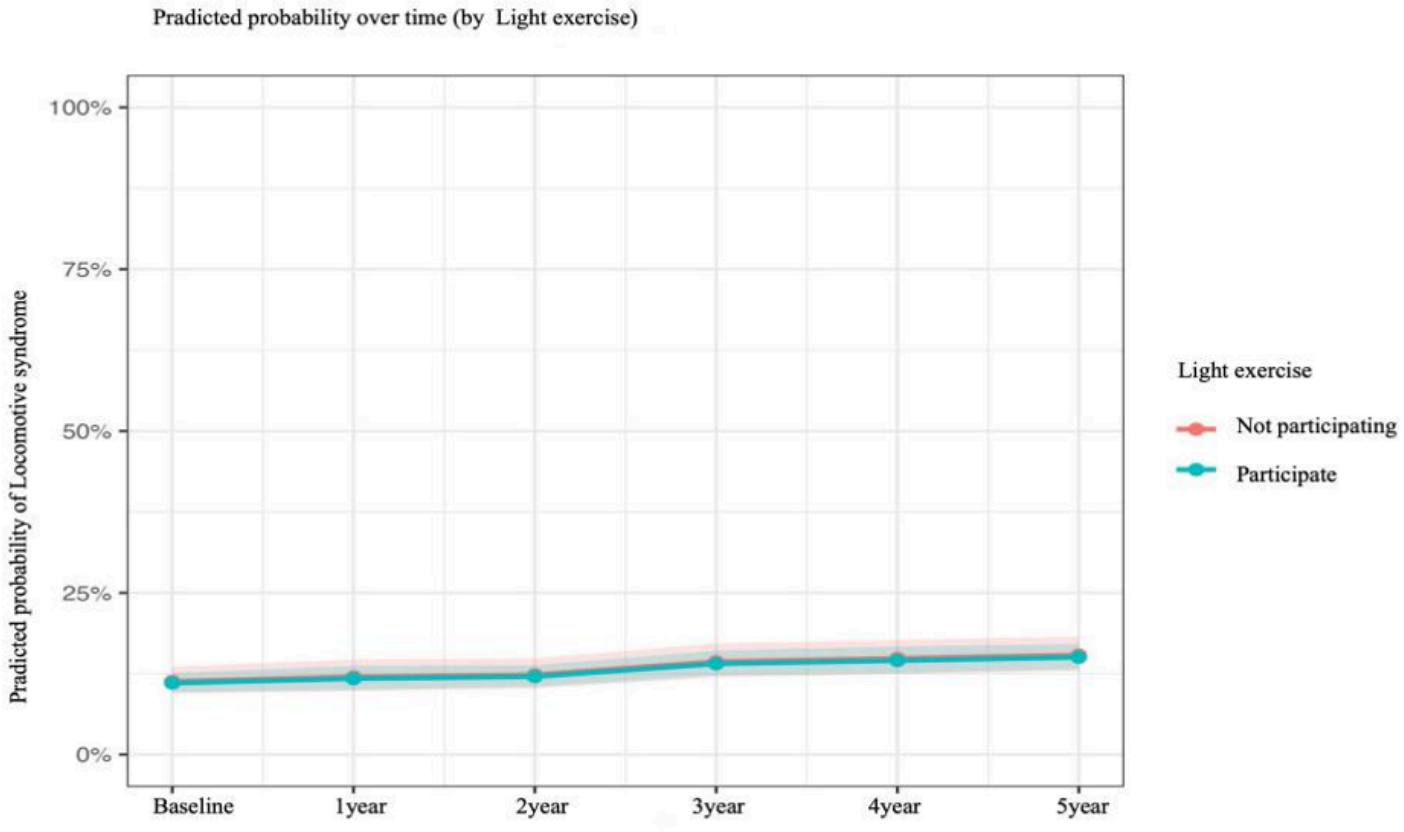


Figure 4. Predicted probability of locomotive syndrome over time according to participation in light exercise.

Figure 4

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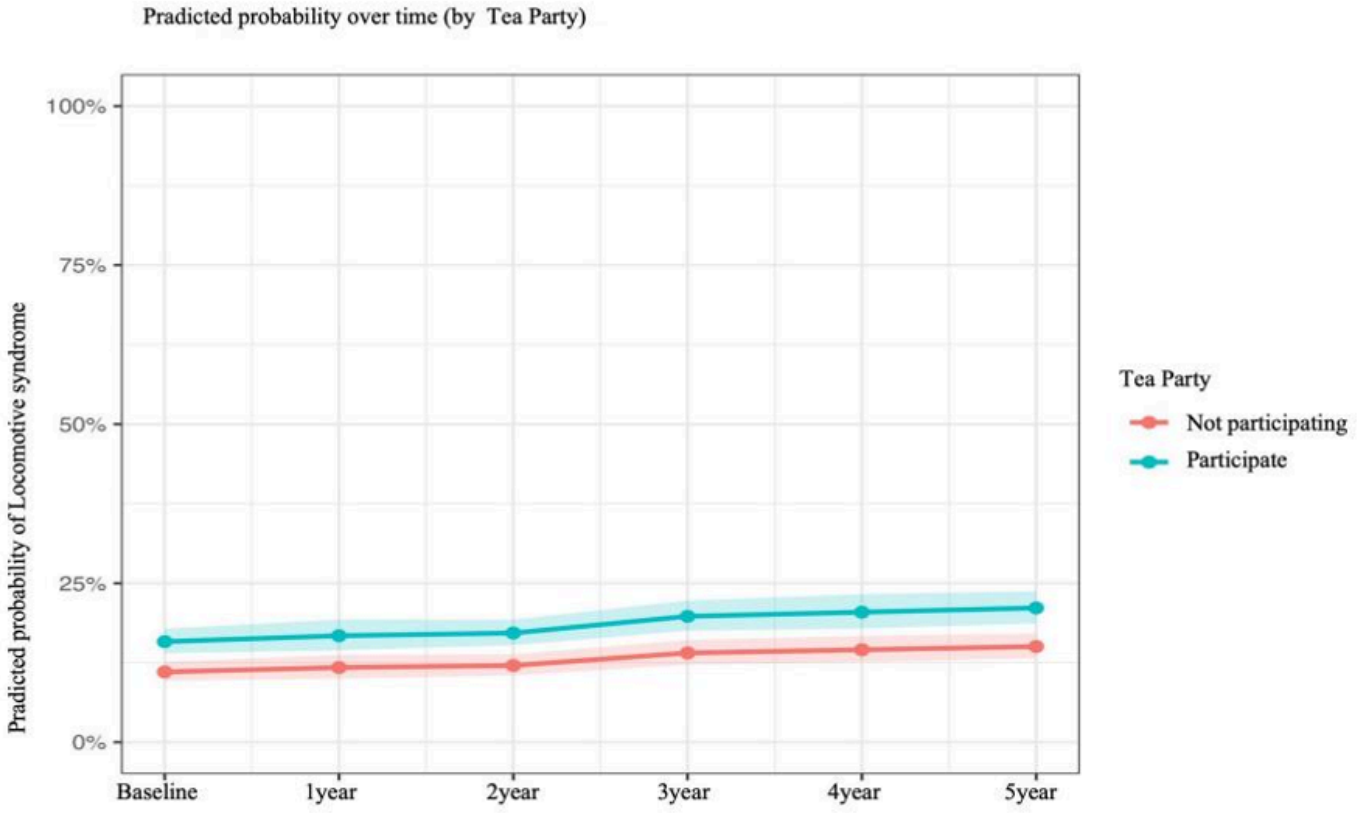


Figure 5. Predicted probability of locomotive syndrome over time according to participation in tea party activities.

Figure 5

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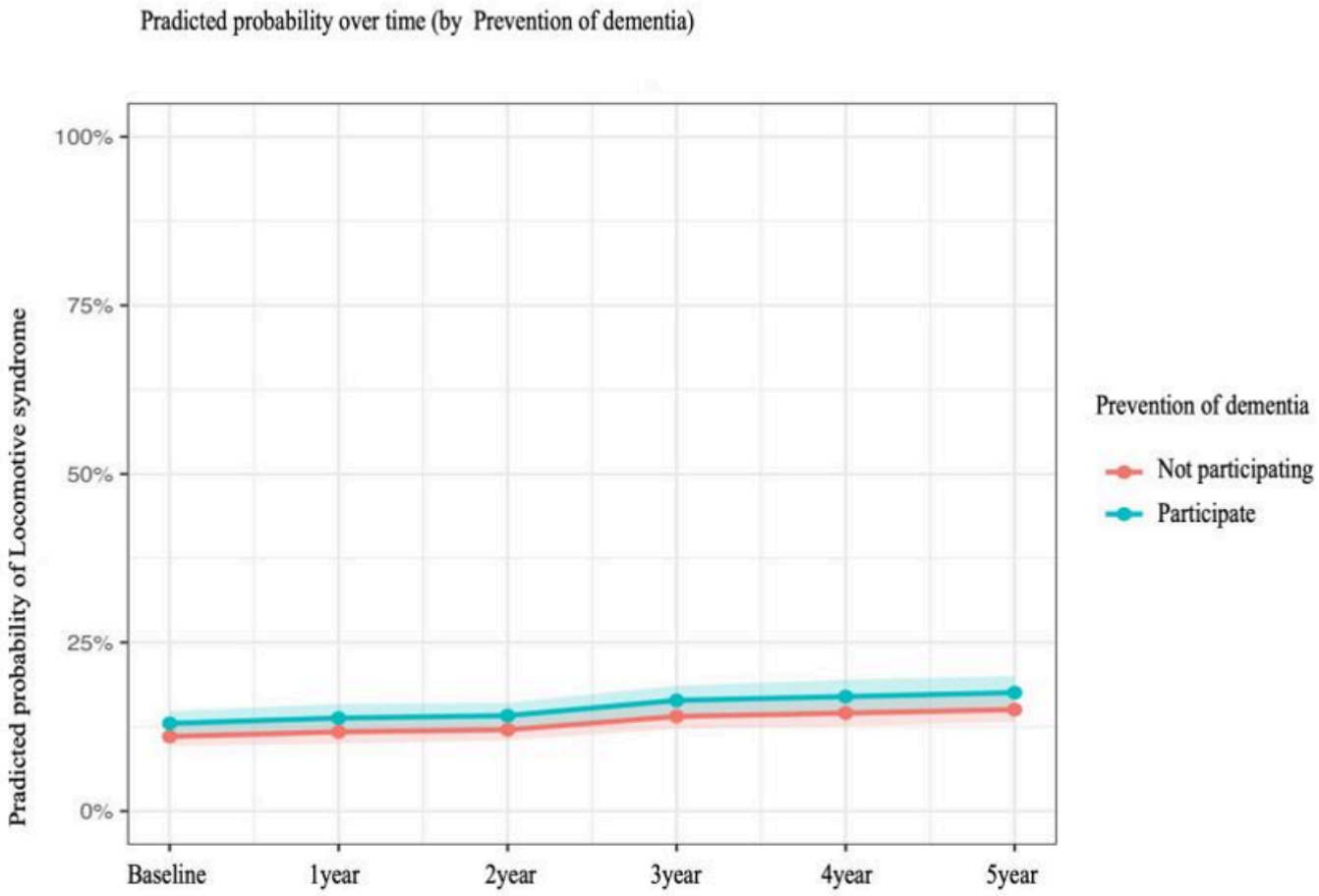


Figure 6. Predicted probability of locomotive syndrome over time according to participation in dementia prevention activities.

Figure 6

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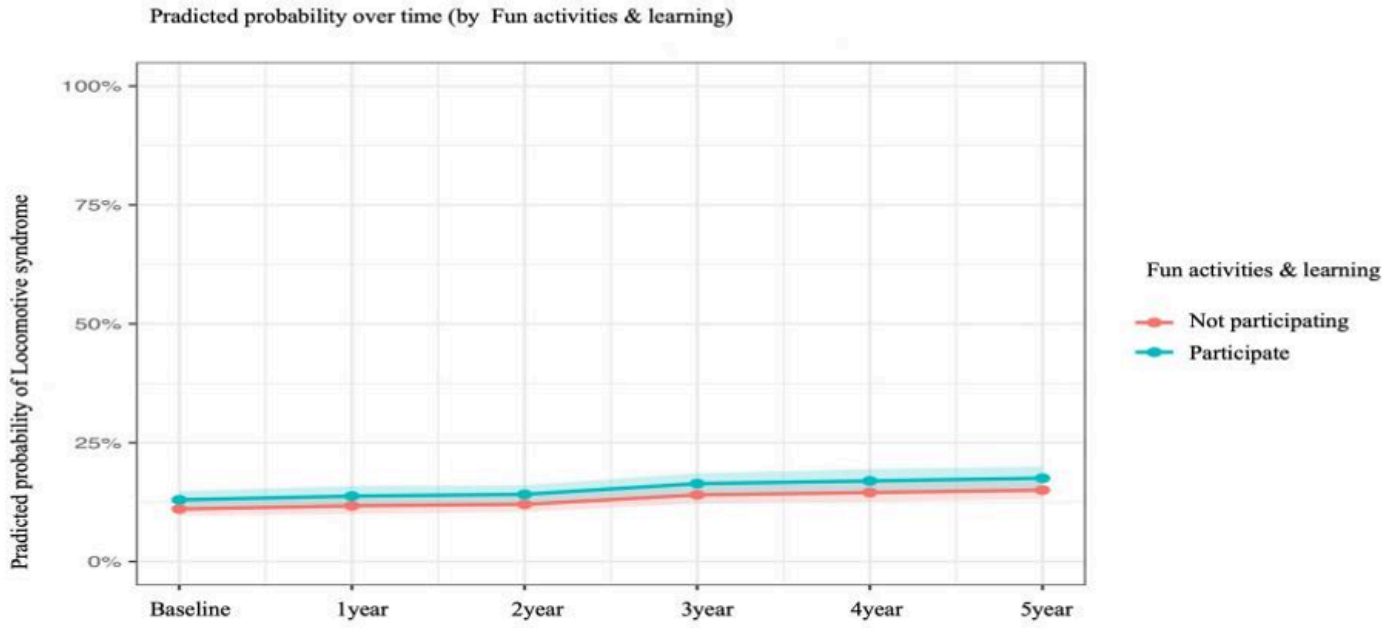


Figure 7. Predicted probability of locomotive syndrome over time according to participation in Fun activities & learning.

Figure 7

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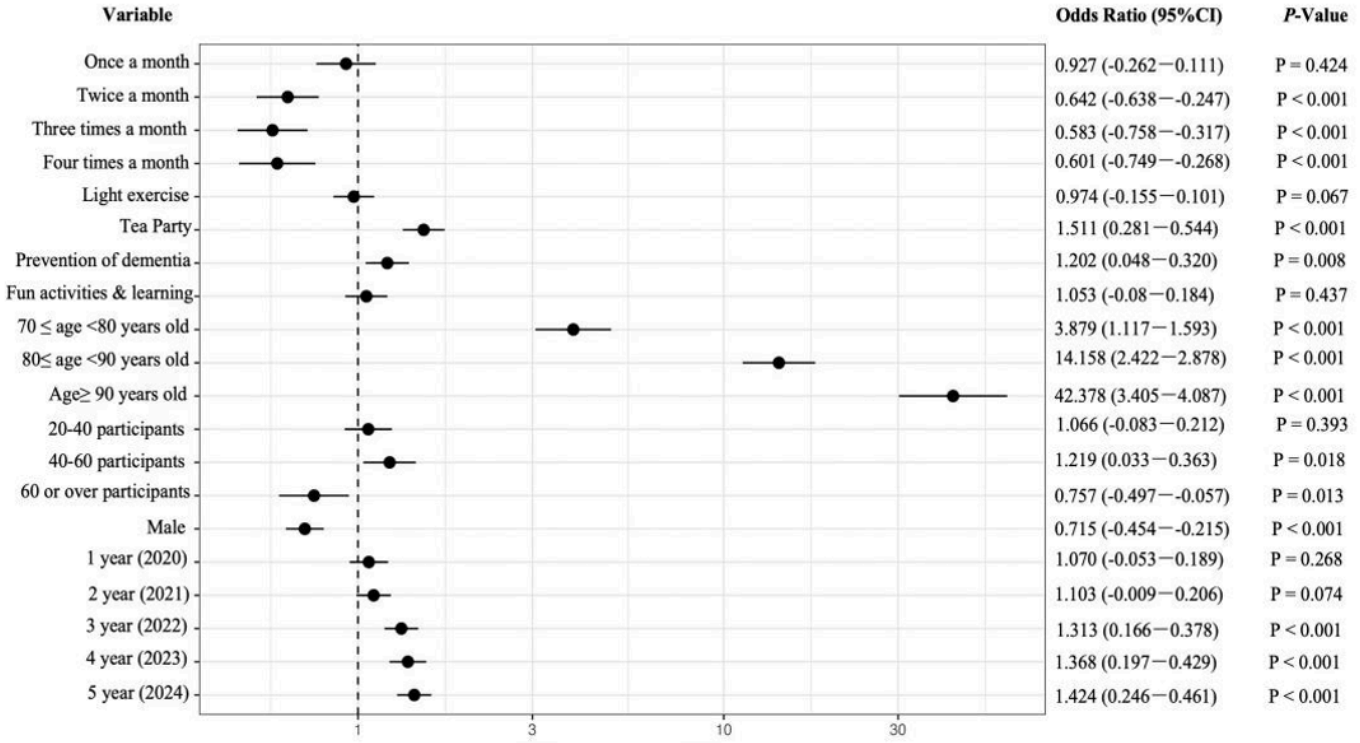


Figure 8. Adjusted odds ratios for locomotive syndrome estimated using a generalized linear mixed model with multiple imputation.

Figure 8

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