The Journal of Aging Research & Lifestyle 14 (2025) 100009

Contents lists available at ScienceDirect

The Journal of Aging Research & Lifestyle

journal homepage: www.elsevier.com/locate/jarlif

Original Research

Centenarian physical functioning evolution and COVID-19 impact: A study in Japan

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ARTICLE INFO

Keywords:
Centenarian
ADL, Mobility
Physical function
Covid-19

ABSTRACT

Background: Studies show that centenarians' physical function and activities of daily living (ADL) levels improved recently. However, it is unclear whether this positive impact has been altered due to COVID-19, causing reduced ADL. This study had two objectives: 1) to investigate whether the physical function of Japanese centenarians has improved over time, and 2) to examine the impact of COVID-19 on centenarians.

Method: The data were collected from research conducted in Kyotango City from 2014 to the present. Kyotango City Hall collected data, including the functional status of all centenarians who reached 100 years of age every year. In this study, we divided nine-year cohort into three periods: 2014–2016 (P1), 2017–2019 (P2), and 2020–2022 (P3). The participation rates were 89 % (n = 100), 78 % (n = 90), and 74 % (n = 114), respectively.

Results: The centenarians' ability to perform activities of daily living (ADL) declined as the cohort aged. For basic activities of daily living (BADL), the proportion of participants classified as independent increased from P1 to P2 and then decreased from P2 to P3 among female centenarians. However, this trend was not observed in male centenarians. Concerning mobility, only the proportion of bedridden centenarians decreased over the three periods. Statistically significant differences in the trends of female centenarians with robust mobility and those with weak mobility were obtained in the three periods.

Conclusion: The proportion of independent female centenarians in both BADL and mobility declined as the cohort aged. The opposite is true for male centenarians. This phenomenon was not affected by COVID-19.

1. Introduction

1.1. Global centenarian surge

Recently, the number of centenarians has surged remarkably. According to 2022 estimates by the United Nations (UN), the global count of centenarians was 593,000. The UN projects a significant increase, estimating 3.7 million centenarians by 2050 [1]. The health status of this rapidly growing population has received widespread attention from centenarian researchers [2,3].

Notably, Japan leads the world in centenarian demographics, with a record-breaking estimate of 92,139 individuals aged 100 or older. According to Japan's Ministry of Health, Labor, and Welfare, women constitute 88.5 % of the centenarian population. Japan has the world's longest life expectancy, which reflects its robust healthcare system [4].

1.2. Research on centenarians abroad

Many researchers have focused on the activities of daily living (ADL) of centenarians worldwide 5–13. It has been proven that ADL scores decline significantly just before death [14,15]. Therefore, assessing an individual's ADLs is crucial not only for predicting outcomes such as nursing home admission, the need for alternative living arrangements, hospitalization, and reliance on paid home care services but also for supporting the well-being of older adults [16].

Studies of centenarians in Western countries have compared late-born centenarians with those from earlier-born cohorts, showing improved physical functioning among later-born populations. For instance, studies in Denmark have shown improvements in the physical function and ADLs among centenarians, particularly in late-born cohorts [8]. Similarly, a study from the Georgia Centenarian Study in the USA compared ADLs between two cohorts and found that the later-born cohort exhibited better ADLs [11].

In contrast, a study of centenarians in Hong Kong compared the physical functioning, mental health, and social engagement of Chinese centenarians between 2011 and 2021/2022. The results indicated that the latter cohort of centenarians exhibited poorer mental health, showed more dependence on others or props on ADLs, and participated in fewer outdoor activities [17]. This finding contrasts with studies on centenarians in Western countries.

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https://doi.org/10.1016/j.jarlif.2025.100009
Received 8 January 2025; Received in revised form 24 February 2025; Accepted 25 February 2025
Available online 11 March 2025

1.3. Research on centenarians in Japan

In Japan, there are many cross-sectional studies on the ADLs of centenarians [18,19]; however, cohort studies have rarely been conducted. Even in the few available studies, opposing trends have been observed in Japan compared to Western countries. Two studies on Okinawan centenarians, one examining centenarians from the 1970s through the 1990s [20], and another comparing centenarians from 1992 to 2000 [21], found declines in physical functioning and ADLs. A study using independent national surveys of centenarians found a rising proportion of bedridden centenarians over a 30-year period from 1972 to 2000 [22]. These findings contrast with studies from Japan and other Western countries.

1.4. Younger older adults are getting stronger

In Japan, the physical functioning of younger older adults has improved compared with those of the same age in the past. Previous studies have shown statistically significant improvements in walking speed and grip strength in male and female aged 65–74 years [23]. Another longitudinal study found that in two cohorts separated by ten years, grip strength, maximum walking speed, and usual walking speed in the later cohort, males and females were functionally younger by 4–11 and 8–11 years, respectively, than those in the earlier cohort [24]. These findings suggest that the physical condition of younger older adults in Japan has dramatically improved compared to the past, leading some scholars to refer to this as a "rejuvenation phenomenon."

1.5. Objective 1

While the physical function of younger older adults has improved compared to that of the earlier cohort, the opposite trend was observed among centenarians. Whether this phenomenon occurs widely across Japan requires further investigation, as well as an explortion of its causes. Additionally, many Japanese studies are outdated compared to more recent international research. Therefore, it is imperative to conduct studies of present-day Japanese centenarians. The first objective of this study was to carefully examine the temporal evolution of physical function among Japanese centenarians over time.

1.6. About Kyotango city

This study was based on a long-term cross-sectional survey of centenarians in Kyotango City, Kyoto Prefecture, Japan. Kyotango City, located at the northernmost tip of Kyoto Prefecture, has a coastal climate characterized by long daylight hours in summer and shorter daylight hours in winter and experiences heavy snowfall. Additionally, the world's oldest living male was from Kyotango [25]. This phenomenon may be related to local lifestyle, dietary habits, and favorable natural environments. Although Kyotango City may not fully represent the centenarian population across all of Japan, it offers a window into the factors contributing to longevity in rural Japan.

1.7. COVID-19 and objective 2

This study began in 2014 and continues to the present day. During this period, the world witnessed the COVID-19 pandemic, which caused significant disruptions in Japan and other countries. One review found that the mental and physical health of older adults was negatively affected during periods of social distancing due to the COVID-19 pandemic [26]. Previous research has shown that the transition from health to disability in older adults is influenced not only by pathological factors such as illness and injury but also by significant factors such as psychological conditions and environmental changes [27]. During the COVID-19 pandemic, Japan issued several advisories encouraging people to stay home, significantly reducing outdoor activities. This environmental change may have substantially affected the daily functional abilities of centenarians. Therefore, it is crucial to investigate whether the previously observed improvements in physical function among centenarians have persisted or been altered since the pandemic. This prompts the question: Has a positive trajectory in physical function among centenarians continued despite the challenges posed by the pandemic? Therefore, the second study objective was to investigate the impact of the COVID-19 pandemic on the physical well-being of centenarians. By thoroughly examining the effects of the pandemic, this study aimed to determine whether centenarians' physical function has changed compared with pre-pandemic conditions.

2. Methods

2.1. Kyotango centenarian study

The Kyotango Centenarian Study aimed to elucidate cohort disparities in the health and functioning of centenarians. Annually, in September, the local government collects data on centenarians born between September 16th and March 31st of the following year except in the first year. In the first year, we surveyed all the centenarians, including those born before September 16th. The survey comprises five components: physical function, mental health, cognitive function, leisure activities, and sociodemographic data. In this study, sex and ADLs were used to analyze physical functioning and mobility.

This study included data from the Kyotango Centenarian Survey conducted from 2014 to 2022. For the analysis, we divided the nine-year survey period into three three-year periods: Period 1 (2014–2016), Period 2 (2017–2019), and Period 3 (2020–2022). These were referred to as P1, P2, and P3.

The number of 100-year-olds in Kyotango City during the three periods were 112, 116, and 155. This study included 100 participants from P1 (89 % participation rate), 90 from P2 (78 % participation rate), and 114 from P3 (74 % participation rate). The exclusion criteria included those who did not want to participate in the survey or were unable to participate for medical reasons, and those with excessive missing values. The proportion of males in the three periods was 14 %, 18 %, and 12 %, respectively (Table 1).

This study utilizes the data collected by Kyotango City as part of the city's operations. The City Hall contacts all centenarians and centenarian candidates annually in September to give a certificate for celebrating 100 years of life and gifts. A city hall staff member visits centenarians and presents them with gifts. Staff verbally explained the purpose of the survey, obtained consent, and then conducted the interview. If centenarians were unable to ansewer questions independtly, data was collected from the proxy respondent. Previously assessed physical, cognitive, and care needs levels for long-term care pensions were also provided by city hall. For the purpose of conducting research using the data collected by city hall, ethical approval was granted by the Graduate School of Human Sciences, Osaka University (HR 29–020).

2.2. ADL questionnaires

ADL was assessed using a self-report or proxy report of 12 physical function tasks (Table 2). This scale includes 12 items to assess the difficulty participants have with physical tasks (e.g., getting in and out of bed, standing up from a chair, keeping a standing position, going to the lavatory). All 12 items were scaled from 0 = completely unable to 3 = without difficulty. For each item, we analyzed the changes over the three periods for both sexes.

2.3. Basic activities of daily living

Five basic activities of daily living (BADL) were selected from these 12 tasks (Table 2) (8). Disability was assessed using a disability score

Table 1
Characteristics of the participants.

		P1[a] (2014–2016)	P2 (2017–2019)	P3 (2020–2022)	[c]*p*-Value
	[b]Total participation rate, N (%)	100 (89 %)	90 (78 %)	114 (74 %)	<.001
	Male participation rate, N (%)	14 (93 %)	16 (64 %)	14 (82 %)	
	Female participation rate, N (%)	86 (89 %)	74 (81 %)	100 (72 %)	
	[d]Male/female participation rate ratio (95 % CI)	1.05 (0.87; 1.23)	0.79 (0.54; 1.03)	1.14 (0.86; 1.41)	
Sex	Female, N (%)	86 (86 %)	74 (82 %)	100 (88 %)	
	Male, N (%)	14 (14 %)	16 (18 %)	14 (12 %)	.534
	Female/Male Ratio	5.7:1	3.0:1	5.9:1	
Year of education	≤8	65 (65 %)	53 (59 %)	40 (35 %)	
	>8	24 (24 %)	18 (20 %)	17 (15 %)	
	Unknown	11 (11 %)	19 (21 %)	57 (50 %)	.411
Age of Participants	Median age (year+month)	99y9m	99y10m	99y11m	
Housing	At home, N (%)	54 (54 %)	43 (48 %)	52 (45 %)	
	Nursing house, N (%)	45 (45 %)	47 (52 %)	62 (54 %)	
	Hospital, N (%)	1 (1 %)	0 (0 %)	0 (0 %)	.546

Notes:.
[a] The year of the survey is indicated in parentheses.
[b] All Kyotango city centenarians whose 100-year-old birthdays are between September 16th of the survey year to March 31st of the next year were invited.
[c] Obtained by the Chi-square test.
[d] The male/female ratio shows a 95 % CI = 95 % Confidence Interval.

derived from five BADLs tasks, which are listed in order of difficulty (from most to least challenging): bathing, dressing, toileting, transferring, and feeding. To compute a disability score, each of the five BADL tasks was converted into a binary variable: "1" indicating independent performance of the activity, and and "0" indicating the need for assistance or not being able to complete the activity alone. Thus, a total score ranging from 0 to 5 was obtained and categorized into three groups: 0–2 (severely disabled), 3–4 (moderately disabled), and 5 (not disabled). These tasks have also been used in previous studies.

2.4. Mobility

Mobility was classified into five hierarchical levels based on four ADL tasks: getting into and out of bed, walking indoors, going outdoors (a short distance), and walking 500 meters without rest. These levels are defined as follows: Level 1: Bedridden; Level 2: Can get into and out of bed independently; Level 3: Can walk indoors independently; Level 4: Can go outdoors for a short distance independently; Level 5: Can walk 500 meters without rest, indicating no mobility impariment. Our study combined Levels 1 and 2 into the "bedridden group," while Levels 3–5 were combined into the "robust group." Fisher's exact test and the Holm-Bonferroni method were performed to assess the association between the two groups and the three time periods.

2.5. Statistical analyses

We used chi-square tests and Fisher's exact tests to determine whether there were significant differences in ADL (each ADL task, mobility, and BADL) between males and females separated over the three periods. When significant differences were detected, we performed post-hoc Holm-Bonferroni corrections to adjust for multiple comparisons. Statistical analyses were performed using SPSS 27.0.1.0 and R 4.4.2 (GUI 1.81 Big Sur ARM build).

3. Results

Table 1 presents the demographic characteristics of the participants. The participation rates for the three periods were 94 %, 80 %, and 75 %, respectively, and there was a statistically significant difference in the participation rates across these periods. The ratio of male to female participation rates varied across periods: in P1, the ratio was 1.05 (95 % CI: 0.87–1.23), indicating similar participation rates between sexes; in P2, the ratio decreased to 0.79 (95 % CI: 0.54–1.03), suggesting lower male participation compared to females; and in P3, the ratio increased to 1.14 (95 % CI: 0.86–1.41), indicating higher male participation relative to females. Despite changes in the sex participation ratios, the overall sex distribution remained relatively stable. In all three periods, the number of female participants exceeded that of male participants. The female-to-male ratio was 3.0 during P2, while it was close to 6.0 in both P1 and P3. Regarding years of education, the proportion of participants with eight years or less of education was higher than that of those with more than eight years in both P1 and P2. Owing to the COVID-19 pandemic, we were unable to conduct face-to-face interviews in 2021 and 2022. As the question on years of education was asked during face-to-face interviews, the missing values of the responses on years of education were higher for P3.

We examined the care need levels among both participants and non-participants. In P1, the percentages of people without a care need level were 10 % and 17 % for participants and non-participants, respectively; in P2, they were 12 % and 8 %; and in P3, they were 9 % and 10 %, respectively. The percentage of people requiring support was 7 % and 17 % in P1 for participants and nonparticipants, respectively; in P2, it was 10 % and 4 %; and in P3, it was 9 % and 10 %, respectively. The percentages of people requiring care were 83 % and 67 % in P1 for participants and non-participants, respectively; in P2, it was 78 % and 88 %, respectively; and in P3, both participants and non-participants had the same percentage of 85 %. There were no significant differences in the percentages of participants and non-participants across the three periods.

In terms of residence, we found that the proportion of participants living at home and in nursing homes was approximately equal across the three periods, with only one person being hospitalized during P1. Among the centenarians who declined to participate, three (25 %) in P1 and seven (17 %) in P3 were hospitalized. For those who declined to participate but were either living at home or in nursing homes, in P1, three people (25 %) were at home and six (50 %) were in nursing homes; in P2, 17 people (65 %) were at home and nine (35 %) were in nursing homes; and in P3, 15 people (37 %) were at home and 19 (46 %) were in nursing homes. There were no significant differences in living conditions between the centenarians who participated and those who declined to participate across the three periods.

3.1. Each ADL item by sex

Table 2 shows sex-specific cohort comparisons for each of the 12 ADL tasks. The proportion of female centenarians who were independent of ADL tasks showed a decreasing trend over the three periods. A statistical significance was found for Q6: Get outdoors (a short distance).

Table 2
Activity of daily living (ADL): Female and male in 3 periods.

Items	Yes, N (%)			With aids, N (%)			With Help of others, N (%)			No, N (%)			[b]*p*-Value
Men	[a]P1(N = 14)	P2(N = 16)	P3(N = 14)	P1(N = 14)	P2(N = 16)	P3(N = 14)	P1(N = 14)	P2(N = 16)	P3(N = 14)	P1(N = 14)	P2(N = 16)	P3(N = 14)	
Q1: Get in and out of bed	9(64.3 %)	8(50.0 %)	8(57.1 %)	0(0.0 %)	1(6.3 %)	1(7.1 %)	2(14.3 %)	5(31.3 %)	3(21.4 %)	3(21.4 %)	2(13.5 %)	2(14.3 %)	.86
Q2: Stand up from the chair	7(50.0 %)	8(50.0 %)	8(57.1 %)	0(0.0 %)	1(6.3 %)	1(7.1 %)	4(28.6 %)	3(18.8 %)	1(7.1 %)	3(21.4 %)	4(25.0 %)	4(28.6 %)	.82
Q3: Keep standing position	5(35.7 %)	8(50.0 %)	7(50.0 %)	3(21.4 %)	1(6.3 %)	1(7.1 %)	3(21.4 %)	3(18.8 %)	2(14.3 %)	3(21.4 %)	4(25.0 %)	4(28.6 %)	.86
Q4: Go to the lavatory	5(35.7 %)	8(50.0 %)	8(57.1 %)	3(21.4 %)	1(6.3 %)	1(7.1 %)	2(14.3 %)	4(25.0 %)	1(7.1 %)	4(28.6 %)	3(18.8 %)	4(28.6 %)	.62
Q5: Walk around indoors	6(42.9 %)	7(43.8 %)	7(50.0 %)	1(7.1 %)	2(12.5 %)	1(7.1 %)	0(0.0 %)	1(6.3 %)	2(14.3 %)	7(50.0 %)	6(37.5 %)	4(28.6 %)	.76
Q6: Get outdoors (a short distance)	2(14.3 %)	2(12.5 %)	5(35.7 %)	3(21.4 %)	1(6.3 %)	2(14.3 %)	0(0.0 %)	5(31.3 %)	1(7.1 %)	9(64.3 %)	8(50.0 %)	6(42.9 %)	.12
Q7: Get up the stairs (about 10 steps)	2(14.3 %)	2(12.5 %)	3(21.4 %)	1(7.1 %)	1(6.3 %)	2(14.3 %)	2(14.3 %)	4(25.0 %)	1(7.1 %)	9(64.3 %)	9(56.3 %)	8(57.1 %)	.85
Q8: Walk 500 m continuously without a break	0(0.0 %)	1(6.3 %)	2(14.3 %)	1(7.1 %)	2(12.5 %)	2(14.3 %)	1(7.1 %)	3(18.8 %)	0(0.0 %)	12(85.7 %)	10(62.5 %)	10(71.4 %)	.43
Q9: Take a bath	4(28.6 %)	5(31.3 %)	6(42.9 %)	0(0.0 %)	0(0.0 %)	0(0.0 %)	1(7.1 %)	3(18.8 %)	1(7.1 %)	9(64.3 %)	8(50.0 %)	7(50.0 %)	.73
Q10: Dressing	5(35.7 %)	7(43.8 %)	7(50.0 %)	0(0.0 %)	0(0.0 %)	1(7.1 %)	4(28.6 %)	3(18.8 %)	2(14.3 %)	5(35.7 %)	6(37.5 %)	4(28.6 %)	.76
Q11: Eating	9(64.3 %)	12(75.0 %)	11(78.6 %)	0(0.0 %)	1(6.3 %)	0(0.0 %)	2(14.3 %)	0(0.0 %)	1(7.1 %)	3(21.4 %)	3(18.8 %)	2(14.3 %)	.62
Q12: Carry shopping bags (about 1.5 L PET bottle)	3(21.4 %)	4(26.7 %)	4(28.6 %)	1(7.1 %)	1(6.7 %)	2(14.3 %)	2(14.3 %)	2(13.3 %)	0(0.0 %)	8(57.1 %)	8(53.3 %)	8(57.1 %)	.85
Women	P1(N = 86)	P2(N = 74)	P3(N = 100)	P1(N = 86)	P2(N = 74)	P3(N = 100)	P1(N = 86)	P2(N = 74)	P3(N = 100)	P1(N = 86)	P2(N = 74)	P3(N = 100)	
Q1: Get in and out of bed	52(60.5 %)	39(52.7 %)	46(46.0 %)	4(4.7 %)	6(8.1 %)	7(7.0 %)	15(17.4 %)	14(18.9 %)	25(25.0 %)	15(17.4 %)	15(20.3 %)	22(22.0 %)	.60
Q2: Stand up from the chair	43(50.0 %)	33(44.6 %)	37(37.0 %)	12(14.0 %)	10(13.5 %)	14(14.0 %)	11(12.8 %)	11(14.9 %)	17(17.0 %)	20(23.3 %)	20(27.0 %)	32(32.0 %)	.72
Q3: Keep standing position	42(48.8 %)	32(43.2 %)	33(33.0 %)	10(11.6 %)	12(16.2 %)	16(16.0 %)	14(16.3 %)	10(13.5 %)	17(17.0 %)	20(23.4 %)	20(27.1 %)	34(34.0 %)	.42
Q4: Go to the lavatory	46(53.5 %)	33(44.6 %)	40(40.0 %)	5(5.8 %)	6(8.1 %)	8(8.0 %)	16(18.6 %)	19(25.7 %)	23(23.0 %)	19(22.1 %)	16(21.6 %)	29(29.0 %)	.62
Q5: Walk around indoors	35(40.7 %)	23(31.1 %)	23(23.0 %)	12(14.0 %)	10(13.5 %)	15(15.0 %)	4(4.7 %)	4(5.4 %)	12(12.0 %)	35(40.7 %)	37(50.0 %)	50(50.0 %)	.14
Q6: Get outdoors (a short distance)	18(20.9 %)	12(16.2 %)	9(9.0 %)	11(12.8 %)	7(9.5 %)	6(6.0 %)	15(17.4 %)	6(8.1 %)	18(18.0 %)	42(48.8 %)	49(66.2 %)	67(67.0 %)	.04
Q7: Get up the stairs (about 10 steps)	10(11.6 %)	6(8.1 %)	5(5.0 %)	0(0.0 %)	5(6.8 %)	3(3.0 %)	9(10.5 %)	4(5.4 %)	11(11.0 %)	67(77.9 %)	59(79.7 %)	81(81.0 %)	.12
Q8: Walk 500 m continuously without a break	7(8.1 %)	4(5.4 %)	2(2.0 %)	3(3.5 %)	6(8.1 %)	3(3.1 %)	3(3.5 %)	3(4.1 %)	4(4.0 %)	73(84.9 %)	61(82.4 %)	91(91.0 %)	.35
Q9: Take a bath	15(17.4 %)	13(17.6 %)	10(10.0 %)	0(0.0 %)	2(2.7 %)	3(3.2 %)	15(17.4 %)	14(18.9 %)	22(22.0 %)	56(65.1 %)	45(60.8 %)	65(65.0 %)	.48
Q10: Dressing	33(38.4 %)	26(35.1 %)	30(30.0 %)	2(2.3 %)	1(1.4 %)	2(2.0 %)	20(23.3 %)	15(20.3 %)	24(24.0 %)	31(36.0 %)	32(43.2 %)	44(44.0 %)	.89
Q11: Eating	59(68.6 %)	44(59.5 %)	55(55.0 %)	2(2.4 %)	2(2.7 %)	1(1.0 %)	14(16.3 %)	11(14.9 %)	25(25.0 %)	11(12.8 %)	17(23.0 %)	19(19.0 %)	.29
Q12: Carry shopping bags (about 1.5 L PET bottle)	14(16.3 %)	12(16.2 %)	14(14.0 %)	4(4.7 %)	4(5.4 %)	7(7.0 %)	7(8.1 %)	3(4.1 %)	4(4.0 %)	61(70.9 %)	55(74.3 %)	75(75.0 %)	.86

Note:.

[a] P1 to P3 stands for period, P1 refers to the period 2014–2016, P2 refers to the period 2017–2019, and P3 refers to the period 2020–2022.

[b] Obtained by the Chi-square test.

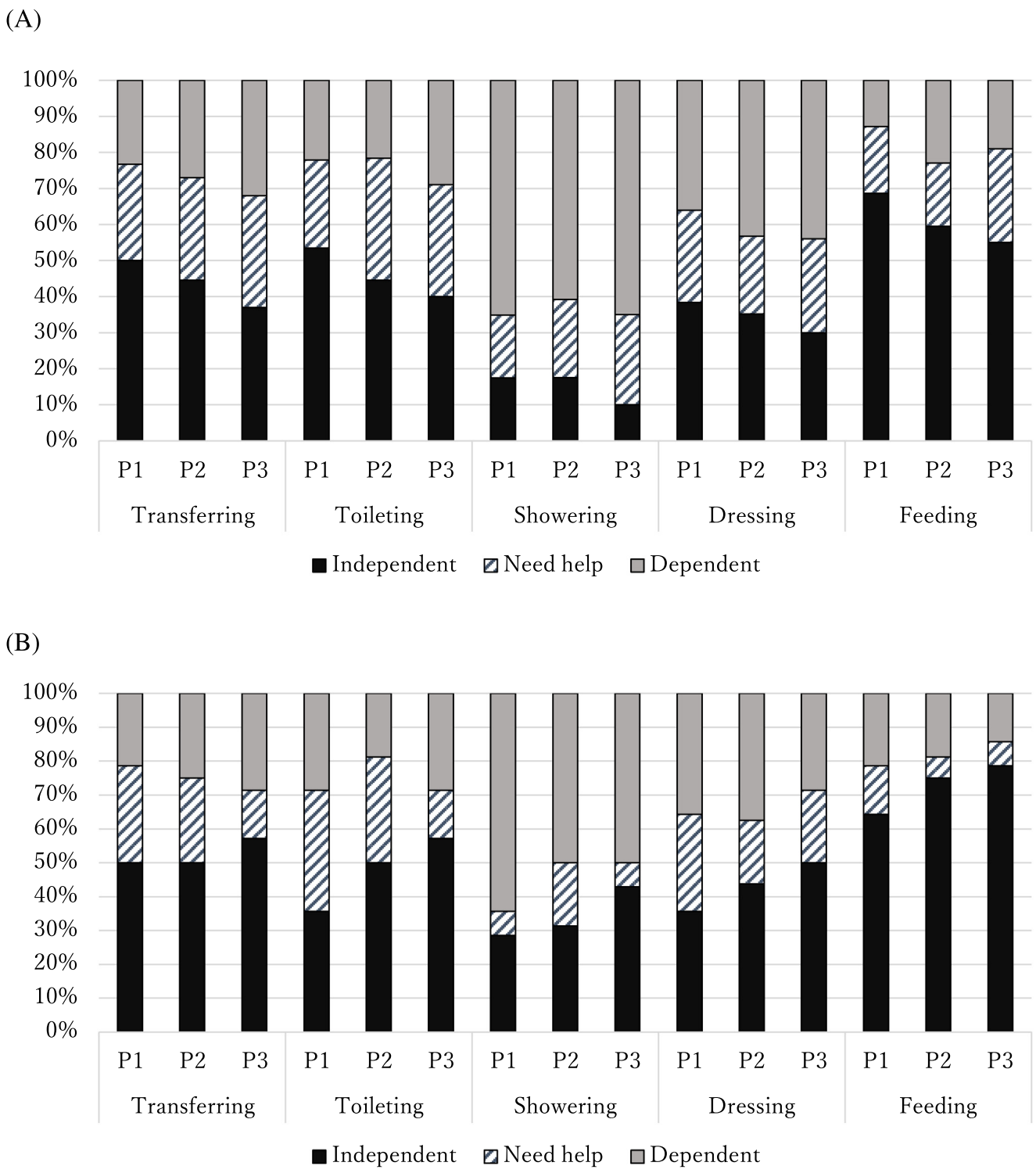

Fig. 1. Basic activities of daily living (BADL): (A) Females in the P1 to P3. P1: $n = 86$. P2n =74. P3 $n = 100$, (B) males in the P1 to P3. P1: $n = 14$. P2n =16. P3 $n = 14$. Proportion that is "Independent": can do the activity independently, "Need help": can do the activity with a little help or is "Dependent": need a lot of help/cannot do the activity at all. Doing an activity independently included using an assistive device if needed, but no help from a person.

By contrast, in male centenarians, the percentage of independence in ADL tasks gradually increased the three periods. However, no statistically significant differences were observed among males.

3.2. BADL

Fig. 1 illustrates the trends in basic activities of daily living (BADL) for both sexes across three periods, derived from the data in Table 2. Among females, there was a decrease over time in the proportion able to perform these activities independently. However, according to Table 3, these changes were not statistically significant. Similarly, while the proportion of independent males showed a reverse trend compared to females, suggesting an increase, this trend also did not reach statistical significance.

Table 3 further details that the highest proportion of independent females was 20 % in period P2, decreasing to 11 % in period P3. Over

Table 3
Disability score derived from basic activities of daily living (BADL) by cohort and sex.

BADL Performed Independently	Female, N (%)			Male, N (%)		
	P1	P2	P3	P1	P2	P3
Total	86	74	100	14	16	14
5 (Nondisabled)	12(14)	15(20)	11(11)	4(29)	5(31)	6(36)
3–4 (Moderately disabled)	38(44)	21(28)	31(31)	3(21)	3(19)	3(21)
0–2 (Severely disabled)	36(42)	38(51)	58(58)	7(50)	8(50)	5(43)
[a]*p*-Value	.16			.92		

Notes: The disability score was calculated based on the five BADL tasks; bathing, dressing, toileting, transferring (stand up from the chair), and feeding. Each BADL task was dichotomized into "0/1″ variables, thereby a total score between 0 and 5 could be obtained (high score indicated independence). The disability sum score was grouped into three; 5 (nondisabled), 3–4 (moderately disabled), and 0–2 (severely disabled).
[a] Obtained by Fisher's exact test.

time, the percentages of independent and moderately disabled females decreased, while the percentage of severely disabled females increased.

For males, despite the initial higher proportion of severe disabilities during P1, there was a decrease by P3. The proportion of independent males increased gradually, but the proportion of moderately disabled males remained relatively stable across the periods. Notably, the considerablysmaller sample size for males, which may impact the robustness of these trends.

3.3. Mobility

We analyzed the mobility of centenarians by categorizing them into five levels: Level 1: bedridden; Level 2: able to independently get in and out of bed; Level 3: able to independently move indoors; Level 4: able to move short distances outdoors, such as in a yard; and Level 5: able to independently move above 500 m which can also be understood as having no mobility restrictions. We divided the nine years of data from 2014 to 2022 into three groups of three years each (P1, P2, and P3) for analysis, with three years of P3 (2019–2022) coinciding with the COVID-19 pandemic. Fig. 2A shows an increasing trend over time in the proportion of female centenarians classified as Level 1 (bedridden). The proportion of those at Level 2 who could get in and out of bed independently showed little change. However, from Level 3 onwards, representing centenarians who can walk indoors to those who can independently walk >500 meters, there was a noticeable annual decline in the proportion of centenarians at Levels 3, 4, and 5. For males, the proportion of Level 1 showed an increasing trend from P1 to P2, followed by a decline at P3. A sharp decline was observed in the proportion of males at Level 2 from P1 to P2 and P3. At Level 3, a significant decrease was noted in P3, whereas the proportion at Level 4 remained relatively stable. Interestingly, centenarians at Level 5, representing those with no mobility issues, appeared only in P3.

We combined the proportions of Levels 1 and 2 to form the "bedridden" group, and the proportions of Levels 3 to 5 to form the "robust" group. As shown in Fig. 2B, an increasing trend in female centenarians and increasing cohort proportions was observed in the frail group, and conversely, a decreasing cohort proportion was observed in the robust group. The opposite trend was observed in the male group: the frail group declined with cohort proportions, and the robust group increased with cohort proportions. However, the trend in males was relatively flat.

The findings indicate a significant association between different cohorts and mobility capabilities in females, with Fisher's exact test yielding a $p < 0.05$. Further analysis using the Holm-Bonferroni method revealed that a statistically significant difference exists only among the female group between P1 and P3. Additionally, the proportion of bedridden females showed a significant decline from P1 to P3 and from P2 to P3, further suggesting that health interventions targeted at bedridden females may have been effective during these periods. Moreover, the proportion of physically independent females significantly decreased in P3, although the statistical significance of this change was lower ($p < 0.1$).

However, the analysis did not show statistically significant differences between the total participants and the male group at different time points. This may suggest that, compared to females, males did not show significant changes in mobility capabilities, or that these changes were not statistically significant.

4. Discussion

4.1. Interpretation of Findings

4.1.1. Analysis of trends in physical function among Japanese centenarians

From our study results, it can be observed that Japanese centenarians exhibit a declining trend in physical functioning as reflected in the ADL items over the years, which further validates the findings of studies in Okinawa [20,21]. Owing to differences in the calculation of ADL scores, a direct comparison of the results is not possible. However, it can be stated that the proportion of centenarians with good physical function is now lower compared to previous generations of centenarians. Regarding sex, females also show a similar declining trend in the proportion of centenarians with good physical function. Conversely, males exhibited the opposite trend. The results showed that the proportion of male centenarians who could perform independently on almost every item of ADL tended to increase over the three time periods. Thus, the proportion of healthy male centenarians has increased annually. This result is consistent with previous studies that have highlighted that male generally exhibit better daily living abilities than female across different cohorts, despite female having a longer lifespan [28–30].

4.1.2. Comparison with findings from studies abroad

Our findings indicate that recent Japanese centenarians are less independent in ADLs than earlier cohorts. This is in direct contrast with the findings of studies conducted in Western countries. A previous study in the United States found that the physical and cognitive functioning of later-born centenarian cohorts was superior to that reported in previous studies [11]. When comparing BADLs among female centenarians in Japan and Denmark [8,9] with our study, we found no significant differences between the two countries. However, a disparity emerged for male centenarians; the proportion of disabled males in Japan (P1:50 %, P2:50 %, P3:43 %) was higher than that in Denmark (1895 cohort: 31 %, 1915 cohort: 35 %). This indicates that although the percentage of disability among Japanese male centenarians has decreased over time, it is still higher than that observed in Denmark.

In short, current Japanese centenarians are not as healthy as past generations. This finding aligns with research from Hong Kong [17], which showed that the average number of ADL tasks for which centenarians were dependent increased from 0.79 in 2011 to 2.79 in 2021.

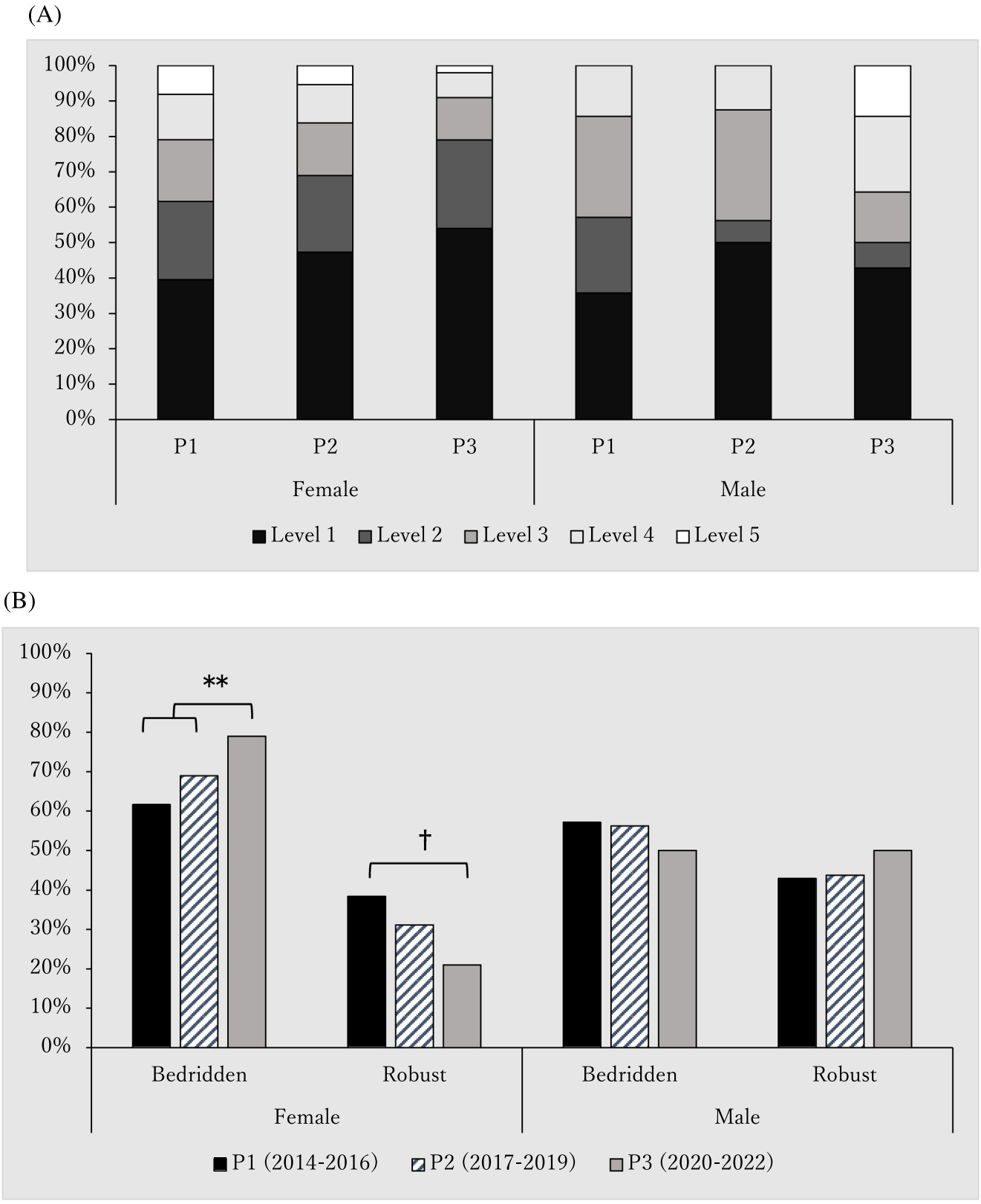

Fig. 2. (A) Comparison of males and females with the percentage of mobility level in each period. Notes: We used "Get in and out of bed," "Walk in the house," "Engage in activities outside," and "Walk 500 m continuously without a break" to devise the mobility levels. The sum of Levels 1–5 for each period was 100 %. (B) Comparison of males and females with bedridden and robust mobility changes from P1 to P3. Week: Set of levels 1 and 2 in Fig. 2(A). Robust: set of levels 3 and 2 in Fig. 2(A). Obtained using Fisher's exact test. ** $p < 0.01$, † $p < 0.1$.

This suggests that centenarians in Asia have become more dependent over time, whereas in Western countries, the opposite trend appears.

A study in Denmark supports the prevailing hypothesis that frailty is the primary cause of death, which explains why there is no increase in the proportion of disabilities in ADLs with age [8,9]. However, the results of this study in Japan do not support this hypothesis. This may be because of the advanced level of nursing care in Japan, which allows bedridden elderly individuals to maintain a basic level of daily life. Gondo highlights in his book that during his research on centenarians in Okinawa, he found that many children of centenarians, even though they were themselves very old, continued to care for their centenarian parents, even feeding them food [31]. This practice surprised his foreign colleagues traveling with him. Such respect and care for older adults have allowed these centenarians, who exhibit disabilities in ADL tasks, to survive. Similarly, the 5-COOP study indicated that, while more human resources were invested in home care in Japan, the actual use of care services at home was relatively limited [32]. Thus, it can be inferred that family care constitutes the majority of daily care for centenarians.

Additionally, previous studies have confirmed that female tend to have more disabilities and diseases than male, and one explanation for sex differences is that, relative to elderly male, female have a higher pro-inflammatory state. Consequently, they are at greater risk of age-related diseases and disabilities [33].

This phenomenon is referred to as the male–female health–survival paradox, also known as the morbidity–mortality paradox or sex paradox, in which females experience more medical conditions and disabilities during their lives, but they unexpectedly live longer than males [34,35]. This paradox is unusual because experiencing disease is expected to increase the likelihood of death [35].

Regarding the mobility of centenarians, a study conducted in the United States in 2018 indicated that 33.3 % of American centenarians could walk independently without assistance, whereas the rate was 22.0 % for Japanese centenarians [9]. In a Danish study, 32 % of the centenarians born in 1895 could walk independently outdoors, and this proportion increased to 43 % among the centenarians born a decade later [9]. In this study, the proportion of centenarians with good mobility across the three periods were 39.0 %, 33.3 %, and 24.8 %, respectively. Regarding sex differences, the proportion of female centenarians with good mobility across the three periods was 38.4 %, 31.1 %, and 21.0 %, respectively, whereas for male centenarians, it was 42.9 %, 43.8 %, and 50.0 %, respectively.

Although these studies used different measurement methods and were conducted over various periods, a simple cross-sectional comparison showed that across all sexes, Danish centenarians had the highest rate of independent walking. Additionally, male centenarians in this study had a higher rate of independent walking than centenarians in other countries. Overall, Japanese centenarians, especially females, had the lowest proportion of individuals who could walk independently. Further cross-cultural studies are required to investigate the reasons for these differences.

4.2. Implications of the COVID-19 Pandemic

In the individual analysis of ADL items, we did not observe any impact of COVID-19 on the physical functioning of centenarians. Therefore, we divided the 12 ADL items into two parts, namely BADL and mobility, to see if the pandemic had any effect.

The results showed that, in the total participant group, only the proportion of centenarians without disabilities in all BADL items increased from P1 to P2, whereas it showed a declining trend in P3, the period coinciding with COVID-19. This implies that only centenarians who were fully independent in their daily lives were affected by the COVID-19 pandemic, with this impact largely stemming from social restrictions. This trend was also observed in centenarian female.

This also indicates that the pandemic has altered the lifestyles of previously healthy elderly individuals, and this lifestyle change has negatively impacted their physical functioning—a phenomenon particularly evident in younger elderly individuals [26]. Moreover, the city of Kyotango, where the survey was conducted, is located in a non-urban area of Japan, where centenarians already face mobility restrictions due to limited transportation options. Therefore, unless they are exceptionally independent, it is difficult for them to leave their homes, especially during the COVID-19 pandemic. As the majority of centenarians in our study were not independent, restrictions on going out did not significantly affect their daily lives.

4.3. Limitations and future directions

Our study was conducted using a questionnaire survey administered by the Kyotango City Government to individuals aged 100 years each year. Like most centenarian surveys, owing to the unique characteristics of this age group, they were unable to complete the questionnaire independently. Therefore, the questionnaire included both subjective responses from the centenarians and objective observations from third parties. Because it is not always possible to fully distinguish between the two during the analysis, this may have affected the interpretation of the results. Araújo et al. found that approximately half of the centenarians expressed high satisfaction with their subjective health, and this attitude was significantly associated with their performance in BADL and Instrumental Activities of Daily Living (IADL) [36]. Therefore, distinguishing between the subjective and objective responses is important for future research. Although the ADL data used in this study have certain limitations, we also possess authoritative data on nursing grade ratings. We conducted a correlation test between subjective ADL scores and objective levels of care, achieving a correlation coefficient as high as 0.8 ($p < 0.001$). Thus, despite the subjective nature of the ADL data, the high correlation with objective care levels significantly assures the credibility of our data.

Additionally, Kyotango City is geographically located on the Sea of Japan side, which experiences colder winters than other regions. Therefore, outdoor activities during winter were significantly reduced, particularly for centenarians. This finding suggests that similar surveys should be conducted in other regions of Japan.

5. Conclusion

5.1. Summary of findings

The overall ADLs of centenarians in Kyotango City, Japan, showed a declining trend from 2014 to 2022, over nine years (three periods). This trend was also observed in female centenarians; however, the opposite trend was observed in male centenarians. That is, the proportion of independent daily living abilities in male centenarians has increased compared with previous generations.

COVID-19 has only affected centenarians who are completely independent in their BADLs. The pandemic had no effect on most centenarians.

5.2. Contribution to the field

This study further supports the health survival paradox theory proposed by previous researchers, which suggests that although female tend to live longer than male, male survivors tend to exhibit better health. Additionally, our findings provide further evidence for Suzuki's research, indicating that the health status of Japanese centenarians is less healthy than that of previous generations. From the perspective of public healthcare, definitive conclusions cannot be drawn. It remains to be determined whether advancements in medical care have allowed more dependent centenarians to survive, or whether there is a need for more comprehensive healthcare for these non-independent centenarians. However, this requires further investigation.

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of the Graduate School of Human Sciences, Osaka University (Approval Number: HR 29–020), allowing the use of data collected by the Kyotango City Hall for academic research purposes. The study complies with the ethical principles of the Declaration of Helsinki and adheres to relevant national ethical guidelines.

Funding

This research received a garant-in-aid from JSPS KAKENHI (23H03888).

Consent for publication

Not applicable.

Availability of data and materials

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

Declaration of generative AI and AI-assisted technologies in the writing process

I have not used any AI at all.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Xinyu Zhang: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis. **Jean-Marie Robine:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Yasuyuki Gondo:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Data curation, Conceptualization.

Acknowledgements

We thank the Kyotango City Hall for contributing to this study.

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