

# Green tea consumption, social network size, and happiness among older adults: a three-year longitudinal study

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## Article

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# Abstract

Green tea is a familiar part of everyday life in Japan, and our previous cross-sectional study found a positive association between green tea consumption and happiness, partly explained by social network size. We examined this Green tea–Social network–Happiness framework longitudinally among 6,701 community-dwelling older Japanese adults from the Japan Gerontological Evaluation Study, followed from 2016 to 2019. Green tea consumption was categorized as < 1, 1, 2–3, or ≥ 4 cups/day; social network size was the number of friends met per month; and happiness was rated on an 11-point scale. After adjustment, baseline green tea consumption was not significantly associated with social network size ( $P = 0.245$ ) or happiness ( $P = 0.328$ ) in 2019. In contrast, social network size in 2019 was strongly associated with concurrent happiness ( $P < 0.001$ ; ≥10 vs 0 friends/month:  $\beta = 0.533$ , 95% CI 0.368–0.698) and showed substantial within-person persistence: 59.9% of participants with ≥ 10 friends/month in 2016 remained in that category in 2019, and 54.6% with no friends in 2016 remained in the zero category. These findings indicate that the cross-sectional Green tea–Social network–Happiness pattern was not reproduced as a simple prospective pathway over three years, whereas the continuity of social connectedness and its association with happiness remained prominent.

## Introduction

Happiness and subjective well-being are important dimensions of health and quality of life throughout the life course, particularly in later life [1–6]. Happiness does not merely reflect the absence of illness. Rather, it may encompass how individuals experience their health, relationships, social circumstances, everyday activities, and lives as a whole [1–6].

As people grow older, social relationships may become increasingly important. Connections with family members, friends, neighbors, and communities can provide companionship, emotional support, a sense of belonging, and opportunities to maintain meaningful roles. Longitudinal studies have suggested that social network characteristics and social connections are associated with subsequent subjective well-being among older adults [7, 8]. Conversely, social isolation and loneliness have been associated with poorer health and well-being outcomes [9–12]. Happiness may also be closely intertwined with the social environment in which people live [13].

Cultural context is relevant when considering happiness. In Japan and other East Asian settings, well-being may contain a particularly strong relational dimension, including harmony with others, connectedness, and interdependence [14–17]. Thus, understanding happiness among older Japanese adults may require attention not only to individual health behaviors but also to the social and cultural contexts in which everyday life unfolds.

Green tea is deeply familiar in Japanese daily life. Previous epidemiological studies have reported associations between green tea consumption and psychological and physical health outcomes. Higher green tea consumption has been associated with lower psychological distress [18], lower risk of

depressive symptoms [19–21], psychological well-being [22], a lower risk of incident functional disability [23], and favorable indicators related to cognitive, oral, cardiovascular, and general health [24–28].

From a biological perspective, green tea contains catechins and other polyphenolic compounds with antioxidant and potentially health-promoting properties [29–33]. These biological pathways provide one possible explanation for an association between green tea consumption and psychological well-being.

In our previous cross-sectional study using data from 15,115 community-dwelling older Japanese adults participating in the 2016 Japan Gerontological Evaluation Study (JAGES), higher green tea consumption was positively associated with subjective happiness [34]. Even after adjustment for social network size and other measured factors, participants who consumed larger amounts of green tea tended to report greater happiness. Mediation analysis further suggested that social network size accounted for part of the observed cross-sectional association [34].

However, a cross-sectional association cannot establish temporal direction. Greater green tea consumption may contribute to well-being, but people who are already happier may also be more likely to maintain familiar daily routines, interact socially, or engage in health-related behaviors that include drinking green tea. Green tea consumption and happiness may also share common underlying determinants, including health, socioeconomic circumstances, lifestyle, and social relationships.

JAGES provides an opportunity to examine social and behavioral determinants of health and well-being longitudinally among community-dwelling older adults in Japan [35]. A longitudinal perspective is particularly important in the present context because adjustment for baseline happiness allows us to ask whether green tea consumption predicts subsequent happiness beyond differences in well-being that were already present at the beginning of follow-up.

Accordingly, the present study examined longitudinal and cross-sectional associations within the Green tea–Social network–Happiness framework among community-dwelling older Japanese adults. Specifically, we examined whether baseline green tea consumption in 2016 was associated with social network size and subjective happiness three years later, characterized within-person change in social network size from 2016 to 2019, and examined the cross-sectional association between social network size and happiness at follow-up in 2019.

Rather than considering green tea consumption in isolation, we sought to understand how this familiar everyday practice may be situated within the broader context of pre-existing well-being, health, social relationships, and daily life.

To the best of our knowledge, this is the first large-scale longitudinal study to examine green tea consumption, social network size, and happiness together over a three-year period among community-dwelling older adults. By extending our previous cross-sectional study to a longitudinal design in 6,701 participants, the present study evaluates the temporal relationships within the Green tea–Social

network–Happiness framework and provides a more rigorous examination of whether the associations observed cross-sectionally persist over time.

## Results

At baseline, mean happiness was 7.32 (SD 1.78). Green tea consumption was < 1 cup/day in 1,254 participants (18.7%), 1 cup/day in 1,068 (15.9%), 2–3 cups/day in 2,327 (34.7%), and ≥ 4 cups/day in 2,052 (30.6%). Overall, 3,451 participants (51.5%) were men. Baseline social network size was 0 friends/month in 430 participants (6.4%), 1–2 in 1,081 (16.1%), 3–5 in 1,624 (24.2%), 6–9 in 959 (14.3%), and ≥ 10 in 2,607 (38.9%). Baseline characteristics according to green tea consumption are summarized descriptively in Table 1.

Table 1  
Baseline characteristics according to green tea consumption (n = 6,701)

| Characteristics               | Total<br>(n =<br>6,701) | < 1<br>cup/day<br>(n = 1,254) | 1 cup/day<br>(n = 1,068) | 2–3<br>cups/day<br>(n = 2,327) | ≥ 4<br>cups/day<br>(n = 2,052) |
|-------------------------------|-------------------------|-------------------------------|--------------------------|--------------------------------|--------------------------------|
| Happiness score, mean<br>(SD) | 7.32<br>(1.78)          | 7.11 (1.90)                   | 7.27<br>(1.78)           | 7.27 (1.71)                    | 7.52 (1.77)                    |
| Social network size, n (%)    |                         |                               |                          |                                |                                |
| 0                             | 430 (6.4)               | 140 (11.2)                    | 79 (7.4)                 | 128 (5.5)                      | 83 (4.0)                       |
| 1–2                           | 1,081<br>(16.1)         | 200 (15.9)                    | 189 (17.7)               | 411 (17.7)                     | 281 (13.7)                     |
| 3–5                           | 1,624<br>(24.2)         | 325 (25.9)                    | 260 (24.3)               | 583 (25.1)                     | 456 (22.2)                     |
| 6–9                           | 959<br>(14.3)           | 157 (12.5)                    | 159 (14.9)               | 325 (14.0)                     | 318 (15.5)                     |
| ≥10                           | 2,607<br>(38.9)         | 432 (34.5)                    | 381 (35.7)               | 880 (37.8)                     | 914 (44.5)                     |
| Male, n (%)                   | 3,451<br>(51.5)         | 818 (65.2)                    | 665 (62.3)               | 1,183 (50.8)                   | 785 (38.3)                     |
| Female, n (%)                 | 3,250<br>(48.5)         | 436 (34.8)                    | 403 (37.7)               | 1,144 (49.2)                   | 1,267 (61.7)                   |
| Age, years, n (%)             |                         |                               |                          |                                |                                |
| <70                           | 2,331<br>(34.8)         | 534 (42.6)                    | 430 (40.3)               | 779 (33.5)                     | 588 (28.6)                     |
| 70–74                         | 2,007<br>(29.9)         | 381 (30.4)                    | 340 (31.8)               | 690 (29.6)                     | 596 (29.0)                     |
| 75–79                         | 1,491<br>(22.2)         | 219 (17.5)                    | 198 (18.5)               | 547 (23.5)                     | 527 (25.7)                     |
| 80–84                         | 661 (9.9)               | 91 (7.3)                      | 77 (7.2)                 | 237 (10.2)                     | 256 (12.5)                     |
| ≥85                           | 211 (3.1)               | 29 (2.3)                      | 23 (2.1)                 | 74 (3.2)                       | 85 (4.1)                       |
| Education, years, n (%)       |                         |                               |                          |                                |                                |
| ≤9                            | 1,579<br>(23.6)         | 299 (23.8)                    | 206 (19.3)               | 575 (24.7)                     | 499 (24.3)                     |
| 10–12                         | 3,014<br>(45.0)         | 550 (43.9)                    | 474 (44.4)               | 1,036 (44.5)                   | 954 (46.5)                     |

Values are mean (SD) or n (%). No P values are presented because Table 1 is intended as a descriptive baseline summary. Social network size indicates the number of friends met per month.

| Characteristics                                                                                                                                                                            | Total<br>(n =<br>6,701) | < 1<br>cup/day<br>(n = 1,254) | 1 cup/day<br>(n = 1,068) | 2–3<br>cups/day<br>(n = 2,327) | ≥ 4<br>cups/day<br>(n = 2,052) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------------|--------------------------|--------------------------------|--------------------------------|
| ≥13                                                                                                                                                                                        | 2,108<br>(31.5)         | 405 (32.3)                    | 388 (36.3)               | 716 (30.8)                     | 599 (29.2)                     |
| Annual household income(USD), n (%)                                                                                                                                                        |                         |                               |                          |                                |                                |
| <10,000                                                                                                                                                                                    | 359 (5.4)               | 63 (5.0)                      | 45 (4.2)                 | 137 (5.9)                      | 114 (5.6)                      |
| 10,000–19,999                                                                                                                                                                              | 1,050<br>(15.7)         | 202 (16.1)                    | 139 (13.0)               | 366 (15.7)                     | 343 (16.7)                     |
| 20,000–29,999                                                                                                                                                                              | 1,713<br>(25.6)         | 331 (26.4)                    | 290 (27.1)               | 607 (26.1)                     | 485 (23.6)                     |
| 30,000–39,999                                                                                                                                                                              | 1,266<br>(18.9)         | 244 (19.5)                    | 200 (18.7)               | 437 (18.8)                     | 385 (18.8)                     |
| ≥40,000                                                                                                                                                                                    | 2,313<br>(34.5)         | 414 (33.0)                    | 394 (36.9)               | 780 (33.5)                     | 725 (35.3)                     |
| Smoking status, n (%)                                                                                                                                                                      |                         |                               |                          |                                |                                |
| Never                                                                                                                                                                                      | 3,825<br>(57.1)         | 556 (44.3)                    | 532 (49.8)               | 1,341 (57.6)                   | 1,396 (68.0)                   |
| Former                                                                                                                                                                                     | 2,166<br>(32.3)         | 527 (42.0)                    | 399 (37.4)               | 751 (32.3)                     | 489 (23.8)                     |
| Current                                                                                                                                                                                    | 710<br>(10.6)           | 171 (13.6)                    | 137 (12.8)               | 235 (10.1)                     | 167 (8.1)                      |
| Alcohol drinking status, n (%)                                                                                                                                                             |                         |                               |                          |                                |                                |
| Never                                                                                                                                                                                      | 3,121<br>(46.6)         | 461 (36.8)                    | 381 (35.7)               | 1,097 (47.1)                   | 1,182 (57.6)                   |
| Former                                                                                                                                                                                     | 643 (9.6)               | 143 (11.4)                    | 105 (9.8)                | 224 (9.6)                      | 171 (8.3)                      |
| Current                                                                                                                                                                                    | 2,937<br>(43.8)         | 650 (51.8)                    | 582 (54.5)               | 1,006 (43.2)                   | 699 (34.1)                     |
| Disease history<br>Yes, n (%)                                                                                                                                                              | 5,439<br>(81.2)         | 1,020<br>(81.3)               | 867 (81.2)               | 1,902 (81.7)                   | 1,650 (80.4)                   |
| No, n (%)                                                                                                                                                                                  | 1,262<br>(18.8)         | 234 (18.7)                    | 201 (18.8)               | 425 (18.3)                     | 402 (19.6)                     |
| Values are mean (SD) or n (%). No P values are presented because Table 1 is intended as a descriptive baseline summary. Social network size indicates the number of friends met per month. |                         |                               |                          |                                |                                |

| Characteristics                                                                                                                                                                            | Total<br>(n =<br>6,701) | < 1<br>cup/day<br>(n = 1,254) | 1 cup/day<br>(n = 1,068) | 2–3<br>cups/day<br>(n = 2,327) | ≥ 4<br>cups/day<br>(n = 2,052) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|-------------------------------|--------------------------|--------------------------------|--------------------------------|
| Living alone<br>Yes, n (%)                                                                                                                                                                 | 860<br>(12.8)           | 168 (13.4)                    | 143 (13.4)               | 286 (12.3)                     | 263 (12.8)                     |
| No, n (%)                                                                                                                                                                                  | 5,841<br>(87.2)         | 1,086<br>(86.6)               | 925 (86.6)               | 2,041 (87.7)                   | 1,789 (87.2)                   |
| Values are mean (SD) or n (%). No P values are presented because Table 1 is intended as a descriptive baseline summary. Social network size indicates the number of friends met per month. |                         |                               |                          |                                |                                |

## Individual change in social network size from 2016 to 2019

Social network size showed substantial persistence over the three-year follow-up (Table 2). Among 2,607 participants who met ≥ 10 friends/month in 2016, 1,561 (59.9%) remained in the ≥ 10 category in 2019. Among 430 participants who met no friends during a typical month in 2016, 235 (54.6%) remained in the zero category in 2019, while 195 (45.4%) moved to a higher category. The ordinal social-network categories in 2016 and 2019 were moderately correlated (Spearman's  $\rho = 0.556$ ,  $P < 0.001$ ). The corresponding within-person transition patterns for all five baseline categories are shown in Table 2.

Table 2  
Transition in social network size from 2016 to 2019 (n = 6,701)

| Social network size in<br>2016(no. of friends<br>met/month)                                                                                                                                                                                                                                                   | 2019: 0              | 2019:<br>1–2         | 2019:<br>3–5         | 2019:<br>6–9         | 2019:<br>≥10           | Total            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------|----------------------|----------------------|----------------------|------------------------|------------------|
| 0                                                                                                                                                                                                                                                                                                             | <b>235</b><br>(54.6) | 116<br>(27.0)        | 42 (9.8)             | 14 (3.3)             | 23 (5.3)               | 430<br>(100.0)   |
| 1–2                                                                                                                                                                                                                                                                                                           | 170<br>(15.7)        | <b>477</b><br>(44.1) | 257<br>(23.8)        | 79 (7.3)             | 98 (9.1)               | 1,081<br>(100.0) |
| 3–5                                                                                                                                                                                                                                                                                                           | 91 (5.6)             | 374<br>(23.0)        | <b>573</b><br>(35.3) | 275<br>(16.9)        | 311<br>(19.1)          | 1,624<br>(100.0) |
| 6–9                                                                                                                                                                                                                                                                                                           | 39 (4.1)             | 128<br>(13.3)        | 291<br>(30.3)        | <b>218</b><br>(22.7) | 283<br>(29.5)          | 959<br>(100.0)   |
| ≥ 10                                                                                                                                                                                                                                                                                                          | 57 (2.2)             | 163<br>(6.2)         | 430<br>(16.5)        | 396<br>(15.2)        | <b>1,561</b><br>(59.9) | 2,607<br>(100.0) |
| <b>Total</b>                                                                                                                                                                                                                                                                                                  | <b>592</b>           | <b>1,258</b>         | <b>1,593</b>         | <b>982</b>           | <b>2,276</b>           | <b>6,701</b>     |
| Cells show n (row %), with percentages calculated within each 2016 social-network category. The final row shows column totals. Social network size indicates the number of friends met per month. Spearman's $\rho$ between the ordinal social-network categories in 2016 and 2019 was 0.556 ( $P < 0.001$ ). |                      |                      |                      |                      |                        |                  |

# Baseline green tea consumption and social network size in 2019

Baseline green tea consumption was not significantly associated with social network size at the three-year follow-up after adjustment for baseline social network size, sex, age, education, annual household income, smoking status, alcohol drinking status, disease history, and living alone (overall  $\chi^2(3) = 4.15$ ,  $P = 0.245$ ; Table 3). Relative to < 1 cup/day, the adjusted odds ratios for belonging to a higher social-network category in 2019 were 1.087 (95% CI 0.932–1.268;  $P = 0.286$ ) for 1 cup/day, 1.055 (95% CI 0.927–1.202;  $P = 0.415$ ) for 2–3 cups/day, and 1.144 (95% CI 0.998–1.312;  $P = 0.053$ ) for  $\geq 4$  cups/day.

Table 3

Association between baseline green tea consumption and social network size at 3-year follow-up (n = 6,701)

| Baseline green tea consumption                                                                                                                                                                                                                    | Adjusted OR | 95% CI      | P value | Overall P value |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|-------------|---------|-----------------|
| < 1 cup/day                                                                                                                                                                                                                                       | 1.000       | Reference   | —       | 0.245           |
| 1 cup/day                                                                                                                                                                                                                                         | 1.087       | 0.932–1.268 | 0.286   |                 |
| 2–3 cups/day                                                                                                                                                                                                                                      | 1.055       | 0.927–1.202 | 0.415   |                 |
| $\geq 4$ cups/day                                                                                                                                                                                                                                 | 1.144       | 0.998–1.312 | 0.053   |                 |
| Ordered logistic regression with social network size in 2019 as the outcome; adjusted for baseline social network size, sex, age, education, annual household income, smoking status, alcohol drinking status, disease history, and living alone. |             |             |         |                 |

Table 4

Associations of green tea consumption and social network size with happiness at 3-year follow-up (n = 6,701)

| Exposure / category                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | $\beta$ | 95% CI       | P value | Overall P value | Model R <sup>2</sup> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|--------------|---------|-----------------|----------------------|
| A. Green tea consumption in 2016(cup/day)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |         |              |         |                 |                      |
| < 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.000   | Reference    | —       | 0.328           | 0.4027               |
| 1                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 0.039   | -0.074–0.152 | 0.497   |                 |                      |
| 2–3                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | -0.014  | -0.113–0.085 | 0.776   |                 |                      |
| $\geq 4$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 0.059   | -0.045–0.162 | 0.265   |                 |                      |
| B. Social network size in 2016(no. of friends met/month)                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |         |              |         |                 |                      |
| 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 0.000   | Reference    | —       | < 0.001         | 0.4027               |
| 1–2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | -0.058  | -0.228–0.112 | 0.505   |                 |                      |
| 3–5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.036   | -0.127–0.199 | 0.667   |                 |                      |
| 6–9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.023   | -0.150–0.197 | 0.792   |                 |                      |
| $\geq 10$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.146   | -0.012–0.304 | 0.070   |                 |                      |
| C. Social network size in 2019(no. of friends met/month)                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |         |              |         |                 |                      |
| 0                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 0.000   | Reference    | —       | < 0.001         | 0.4079               |
| 1–2                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.254   | 0.092–0.415  | 0.002   |                 |                      |
| 3–5                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.344   | 0.182–0.505  | < 0.001 |                 |                      |
| 6–9                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 0.458   | 0.284–0.631  | < 0.001 |                 |                      |
| $\geq 10$                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 0.533   | 0.368–0.698  | < 0.001 |                 |                      |
| Linear regression with happiness score in 2019 as the outcome and robust standard errors. Panel A adjusted for baseline happiness, baseline social network size, sex, age, education, annual household income, smoking status, alcohol drinking status, disease history, and living alone. Panel B used the same fully adjusted model. Panel C additionally included social network size in 2019 and retained baseline happiness, baseline social network size, baseline green tea consumption, and the same covariates. |         |              |         |                 |                      |

## Green tea, social network size, and happiness in 2019

Baseline green tea consumption was not independently associated with happiness in 2019 after adjustment for baseline happiness, baseline social network size, and covariates (overall  $F(3,6675) = 1.15$ ,  $P = 0.328$ ; Table 4A). Compared with < 1 cup/day, the adjusted regression coefficients were 0.039 (95% CI - 0.074–0.152;  $P = 0.497$ ) for 1 cup/day, - 0.014 (95% CI - 0.113–0.085;  $P = 0.776$ ) for 2–3 cups/day, and 0.059 (95% CI - 0.045–0.162;  $P = 0.265$ ) for  $\geq 4$  cups/day.

Baseline social network size was associated with happiness in 2019 as an overall factor ( $F(4,6675) = 4.73$ ,  $P < 0.001$ ; Table 4B), although individual category contrasts were imprecise; for  $\geq 10$  versus 0 friends/month,  $\beta = 0.146$  (95% CI - 0.012–0.304;  $P = 0.070$ ). When social network size measured in 2019 was included, a strong graded association with concurrent happiness was observed (overall  $F(4,6671) = 12.66$ ,  $P < 0.001$ ; Table 4C). Relative to 0 friends/month, coefficients were 0.254 (95% CI 0.092–0.415;  $P = 0.002$ ) for 1–2 friends/month, 0.344 (95% CI 0.182–0.505;  $P < 0.001$ ) for 3–5, 0.458 (95% CI 0.284–0.631;  $P < 0.001$ ) for 6–9, and 0.533 (95% CI 0.368–0.698;  $P < 0.001$ ) for  $\geq 10$ . Because social network size and happiness in this analysis were both measured in 2019, this finding represents a contemporaneous association and should not be interpreted as a temporally ordered causal effect.

## Integrated longitudinal pattern

Figure 1 summarizes the longitudinal and cross-sectional associations among green tea consumption, social network size, and happiness. The prospective associations of baseline green tea consumption with social network size in 2019 and happiness in 2019 were not statistically significant after adjustment. In contrast, social network size showed persistence over time, and larger social network size was strongly associated with higher concurrent happiness in 2019; because both measures were assessed in 2019, the direction of this cross-sectional association cannot be inferred.

Additional analyses supported this interpretation. When the ordered categories were treated as ordinal variables, there was no evidence of a linear trend between baseline green tea consumption and happiness in 2019 ( $P$  for trend = 0.405), whereas both baseline social network size ( $P$  for trend < 0.001) and social network size in 2019 ( $P$  for trend < 0.001) showed positive trends with happiness. There was no evidence that the association between baseline green tea consumption and happiness differed according to baseline social network size ( $P$  for interaction = 0.976). An exploratory interaction using social network size measured in 2019 was also not statistically significant ( $P$  for interaction = 0.219). In addition, generalized ordered-logit diagnostics did not indicate a material violation of the proportional-odds assumption for the ordered logistic model; accordingly, the prespecified ordered logistic regression was retained as the primary analysis.

Sensitivity analyses were also conducted using change in happiness from 2016 to 2019 and a dichotomized follow-up happiness outcome (0–7 versus 8–10 points). In the change-score model, the overall multivariable model explained little variation in change ( $R^2=0.005$ ; overall  $P = 0.147$ ). These analyses were treated as supportive rather than primary because the main longitudinal model directly adjusted follow-up happiness for baseline happiness.

## Discussion

In this three-year longitudinal study of 6,701 community-dwelling older Japanese adults, the Green tea–Social network–Happiness pattern observed in our previous cross-sectional study was not reproduced as a simple prospective pathway. Baseline green tea consumption was not independently associated with social network size or happiness three years later after adjustment for baseline status and other covariates. In contrast, the social dimension of the framework remained prominent: social network size showed substantial within-person persistence from 2016 to 2019, while larger social network size and higher happiness were strongly associated cross-sectionally at follow-up in 2019. Because these two follow-up measures were assessed at the same time, the direction of this association cannot be inferred.

To the best of our knowledge, this is the first large-scale longitudinal study to investigate green tea consumption, social network size, and happiness together over a three-year period among community-dwelling older adults. This study therefore represents a direct longitudinal extension of our previous cross-sectional work, using a consistent analytical sample of 6,701 participants to examine the temporal relationships among these three factors.

The persistence of social connectedness is an important finding of the present study. Among 2,607 participants who met  $\geq 10$  friends per month in 2016, 1,561 (59.9%) remained in the  $\geq 10$  category in 2019. At the other end of the distribution, among 430 participants who met no friends in a typical month in 2016, 235 (54.6%) remained in the zero category three years later. These patterns indicate that social network size was neither completely fixed nor simply transient. Rather, for many older adults, the degree of contact with friends appeared to show continuity over time, while a substantial proportion also moved to different network categories.

This continuity may be relevant to well-being because social relationships are embedded in everyday life. Repeated opportunities for conversation, companionship, reciprocal support, shared activities, and participation in familiar social settings may accumulate over time. Conversely, persistently limited contact may reflect or reinforce circumstances in which opportunities for social exchange are fewer. The present data do not establish causal direction, and the association between social network size and happiness measured in 2019 is contemporaneous. Nevertheless, the coexistence of social-network persistence and a graded association between 2019 social network size and happiness suggests that the continuity of social connectedness deserves attention when considering well-being in later life.

The present study extends our previous cross-sectional findings [34]. The two studies address different questions and should therefore be interpreted together rather than as contradictory results. The cross-sectional study showed that greater green tea consumption, larger social networks, and greater happiness tended to coexist in 2016, with social network size accounting for part of the observed green tea–happiness association. The present longitudinal study asked a more stringent question: whether green tea consumption at baseline predicted subsequent social network size or happiness beyond differences that were already present at baseline. Those prospective green-tea paths were not statistically significant after adjustment.

Adjustment for baseline happiness is particularly important for interpreting the green tea–happiness association. In the fully adjusted model, baseline green tea consumption was not independently associated with happiness three years later. This finding suggests that the positive cross-sectional pattern observed previously should not be interpreted as evidence that greater green tea consumption itself leads to higher subsequent happiness; pre-existing well-being and the broader circumstances accompanying it remain important considerations. The absence of a dose-response trend and the lack of evidence for interaction with baseline social network size further support the interpretation that baseline green tea consumption was not a clear independent predictor of subsequent happiness in this cohort.

Several mechanisms may nevertheless contribute to the cross-sectional association observed previously. Green tea contains catechins and other polyphenolic compounds with antioxidant properties [29–33]. Previous studies have reported associations between higher green tea consumption and lower psychological distress or depressive symptoms [18–22], as well as favorable physical-health outcomes [23–28]. Prospective studies in Japanese populations have also associated green tea consumption with mortality and cardiovascular outcomes [36, 37]. These physical and psychological characteristics may themselves contribute to subjective well-being.

At the same time, green tea drinking is an everyday practice that may occur within a social and cultural context. A cup of tea may be enjoyed alone as part of a familiar routine, or shared during conversation with family, friends, or neighbors. Our data measured the amount of green tea consumed, but not with whom it was consumed, where it was consumed, or what meaning the occasion held for the individual. Green tea consumption may therefore function partly as a marker of broader daily routines and social circumstances that are not fully captured by the quantity consumed.

Social relationships themselves are multidimensional. The measure used in this study represented the number of friends met during a typical month, but did not assess emotional closeness, mutual support, trust, reciprocity, loneliness, belonging, or the quality of those encounters. Two people in the same social-network category may therefore experience their relationships very differently. Longitudinal research suggests that social network characteristics and contact frequency may help sustain subjective well-being in older age [7, 8], while network structure, social engagement, and emotional support may have distinct relationships with health and well-being [38].

The transition results also suggest a useful direction for future research. With three or more repeated measurements, social connectedness can be considered not only as a baseline characteristic or a follow-up correlate, but as a trajectory. Examining persistently large, persistently small, increasing, and decreasing social networks alongside repeated measures of green tea consumption and happiness could help clarify whether the Green tea–Social network–Happiness framework reflects stable personal and social circumstances, changes over time, or both.

The present study has several strengths. First, its longitudinal design enabled the temporal relationship between baseline green tea consumption and subsequent outcomes to be examined. Second,

adjustment for baseline happiness and baseline social network size addressed important limitations of cross-sectional analysis. Third, the study retained the same conceptual Green tea–Social network–Happiness framework as the previous report while adding within-person information on social-network change. Fourth, a broad range of demographic, socioeconomic, behavioral, health-related, and social variables was considered. Fifth, the proportional-odds assumption underlying the ordered logistic analysis was examined in a generalized ordered-logit diagnostic analysis. Finally, the complete-case analytic sample was kept consistent at  $n = 6,701$  across the principal analyses and figures, facilitating coherent interpretation of the longitudinal findings.

Several limitations should also be considered. First, green tea consumption was self-reported, and information on cup volume, brewing strength, tea variety, timing of consumption, the social circumstances of tea drinking, or changes in consumption during follow-up was unavailable. Second, happiness was assessed using a single global question; well-being is multidimensional and may also encompass life satisfaction, affect, meaning, purpose, and relational aspects. Third, residual and unmeasured confounding cannot be excluded, including personality, physical activity, overall dietary patterns, cognitive function, stressful life events, caregiving experiences, and community participation. Fourth, loss to follow-up and the complete-case restriction may have introduced selection bias. Fifth, social network size captured frequency of contact with friends but not relationship quality, support, loneliness, trust, or reciprocity. Finally, because social network size and happiness in 2019 were measured at the same follow-up wave, their association should not be interpreted as a temporally ordered causal effect.

Taken together, these findings shift the emphasis of the longitudinal Green tea–Social network–Happiness framework. The strongest signal over three years was not an independent prospective effect of baseline green tea consumption, but the continuity of social connectedness and its close relationship with happiness. This perspective does not reduce happiness to the number of social contacts. Rather, it highlights that well-being in later life may be intertwined with the relationships, routines, and social environments that are sustained—or change—across time.

In conclusion, higher baseline green tea consumption was not independently associated with larger social networks or greater happiness three years later after baseline status and other measured factors were taken into account. Social network size, however, showed substantial within-person persistence, and larger social networks at follow-up were strongly associated with higher concurrent happiness. These findings refine our previous cross-sectional observations and support future studies using repeated measurements to examine green tea consumption, social connectedness, and happiness as interrelated trajectories across later life.

## Methods

### Participants

This three-year longitudinal study used data from the Japan Gerontological Evaluation Study (JAGES) conducted in 2016 and 2019. The baseline population consisted of community-dwelling older adults aged 65 years or older participating in the 2016 JAGES survey. Of the 20,835 participants initially considered, 41 were excluded because of inconsistencies in age information, leaving 20,794 participants. Subsequently, 2,432 participants were excluded: 1,185 who required nursing care or assistance in daily life and 1,247 with missing information regarding the need for nursing care or assistance. This resulted in 18,362 participants who reported no need for nursing care or assistance and had available information on care needs.

A further 4,299 participants were excluded because of missing data on variables required for the baseline complete-case analysis, leaving 14,063 participants with complete baseline data. Of these, 7,002 participants were successfully matched to the 2019 follow-up survey using the common unique individual identifier, whereas 7,061 could not be matched to the follow-up survey.

For the present longitudinal analyses, participants were additionally required to have complete data on the variables used at follow-up, including social network size and happiness in 2019. After excluding participants with missing follow-up variables, the final complete-case analytical sample consisted of 6,701 participants. The same analytical sample was used consistently across the principal analyses to facilitate comparability of the results.

## **Dependent Variable**

The primary dependent variable was subjective happiness at follow-up in 2019. Happiness was assessed using a single-item 11-point scale ranging from 0 (very unhappy) to 10 (very happy), with higher scores indicating greater subjective happiness. The 2019 happiness score was treated as a continuous outcome in the main longitudinal analyses. Baseline happiness measured in 2016 was included as an adjustment variable to account for pre-existing differences in subjective well-being and to examine the association of baseline green tea consumption with subsequent happiness more carefully.

## **Independent Variables**

The primary independent variable was green tea consumption at baseline in 2016, categorized as < 1, 1, 2–3, or ≥ 4 cups/day, with < 1 cup/day used as the reference category. Social network size was assessed in both 2016 and 2019 based on the number of friends met during a typical month and categorized as 0, 1–2, 3–5, 6–9, or ≥ 10 friends. Baseline social network size was included to account for pre-existing differences in social connectedness, while social network size in 2019 was examined in relation to concurrent happiness at follow-up. These variables were used to investigate the longitudinal and cross-sectional associations within the Green tea–Social network–Happiness framework.

## **Covariates**

Baseline covariates included sex, age, social network size (number of friends met per month: 0, 1–2, 3–5, 6–9, or  $\geq 10$ ), years of education ( $\leq 9$ , 10–12, or  $\geq 13$  years), equivalent annual household income (USD < 10,000, 10,000–19,999, 20,000–29,999, 30,000–39,999, or  $\geq 40,000$ ; 100 yen = 1 USD), smoking status (never, former, or current), drinking status (never, former, or current), disease history (yes/no), and living alone (yes/no). Age was categorized as 65–69, 70–74, 75–79, 80–84, or  $\geq 85$  years. All categorical covariates were modeled using the categories shown in Table 1.

## Statistical Analyses

Baseline characteristics were summarized descriptively using means and standard deviations or frequencies and percentages, without P values in Table 1. Within-person transitions in social network size from 2016 to 2019 were summarized using row percentages, and the ordinal categories at the two waves were additionally compared using Spearman's rank correlation. The association between baseline green tea consumption and social network size in 2019 was examined using ordered logistic regression adjusted for baseline social network size and covariates. The proportional-odds assumption was examined in a generalized ordered-logit diagnostic analysis; because the diagnostic tests did not indicate a material violation, the ordered logistic model was retained as the primary model. Associations with happiness in 2019 were examined using linear regression with robust standard errors. The green tea model adjusted for baseline happiness, baseline social network size, and covariates. Baseline social network size was evaluated in the same model. A further model included social network size in 2019 to characterize its contemporaneous association with happiness while retaining baseline happiness, baseline social network size, baseline green tea consumption, and covariates. Overall effects of categorical exposures were evaluated using joint Wald tests. Linear trends were examined by entering the ordered categories as ordinal variables. Potential effect modification was examined using interaction terms between green tea consumption and social network size, with joint Wald tests for the interaction terms. Sensitivity analyses included a change-score model for happiness (2019 minus 2016) and logistic regression after dichotomizing follow-up happiness as 0–7 versus 8–10 points. All principal analyses used the same complete-case sample of 6,701 participants. All tests were two-sided, and  $P < 0.05$  was considered statistically significant. All analyses were conducted using Stata 18 software (Stata Corp, College Station, TX, USA), and a two-sided test with  $p < 0.05$  was considered significant.

## Declarations

**Ethical considerations:** The study was conducted in accordance with the Declaration of Helsinki. Ethical approval was obtained from the Ethics Committee of the National Center for Geriatrics and Gerontology (Approval No. 992), Chiba University (Approval No. 2493), and Hamamatsu University School of Medicine (Approval No. 91-123). Informed consent was obtained from all participants involved in the study.

**Data availability:** Data are not open to the public due to ethical concerns. Data from the JAGES study may be requested from the JAGES management committee ([dataadmin@jages.net](mailto:dataadmin@jages.net)).

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**Competing interests:** The authors declare no competing interests.

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Figures

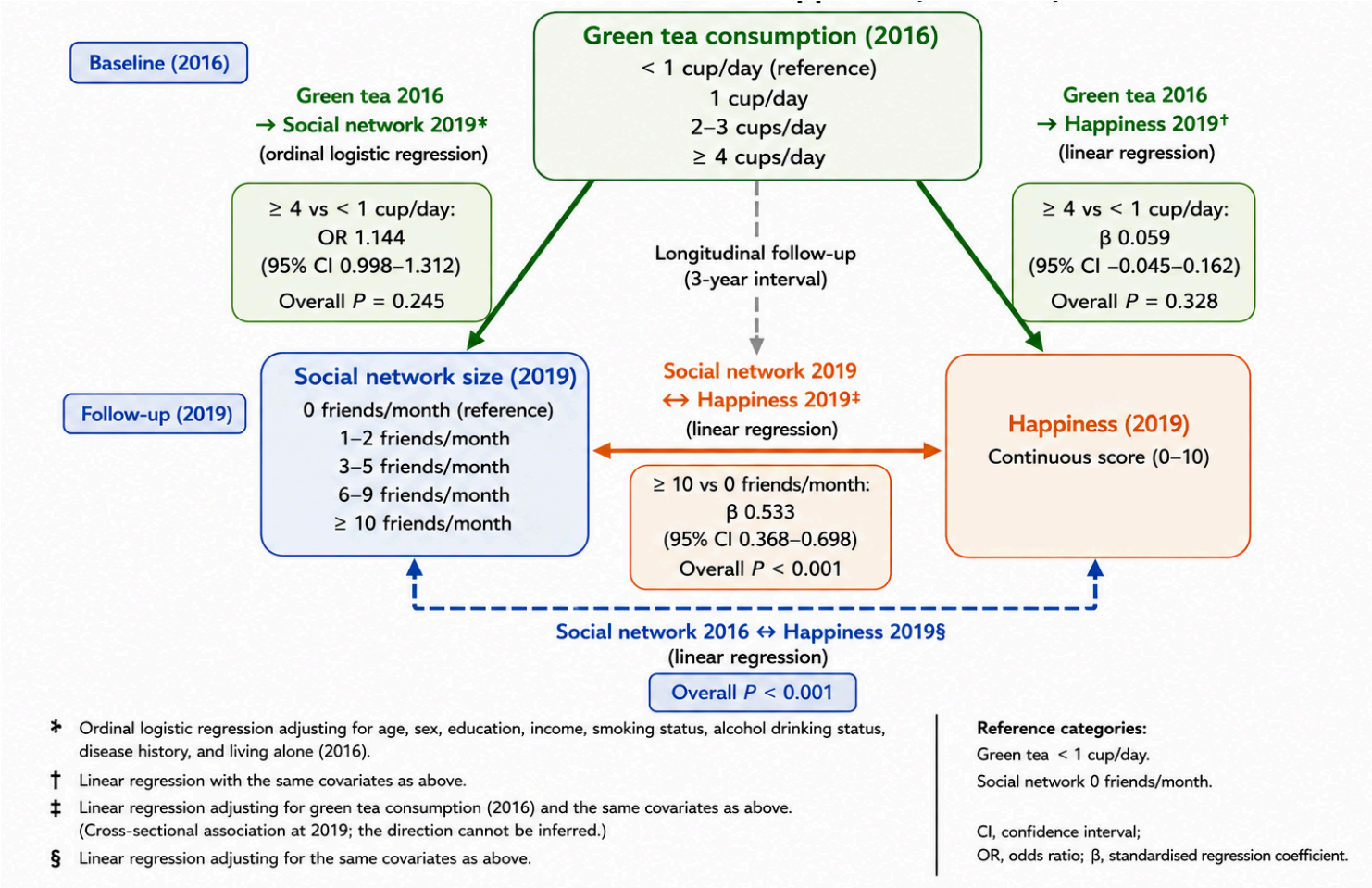


Figure 1

Longitudinal and cross-sectional associations among green tea consumption, social network size, and happiness ( $n=6,701$ ). The prospective associations of green tea consumption in 2016 with social network size and happiness in 2019 are longitudinal. The association between social network size and happiness measured in 2019 is cross-sectional; therefore, its direction cannot be inferred and it should not be interpreted as a temporally ordered causal effect.

Generative artificial intelligence (ChatGPT, OpenAI) was used solely to assist with the visual preparation and layout of Figure 1, based on the conceptual framework developed by the authors. The scientific content, interpretation, and final figure were reviewed and verified by the authors, who take full responsibility for its accuracy and content.