**Title Page**

**The type of manuscript:** Regular Article

**Title:** Acceptable walking time as an indicator of walking behavior among the Japanese working-age population: A cross-sectional study

**Authors:** Yoshito Kamiya [1,2], Akira Kyan [3,4*], Minoru Takakura [5]

**Institutions:**

[1] Department of Sports and Health, Faculty of Human Health Sciences, Meio University, 1220-1 Biimata, Nago, Okinawa 905-8585, Japan

[2] Graduate School of Health Sciences, University of the Ryukyus, A-building 07-1100, 1076 Kiyuna, Ginowan, Okinawa 901-2720, Japan

[3] Faculty of Medicine, University of the Ryukyus, A-building 07-1100, 1076 Kiyuna, Ginowan, Okinawa 901-2720, Japan

[4] Graduate School of Medicine and School of Public Health, Kyoto University, Yoshida-Konoecho, Sakyo-ku, Kyoto-shi, Kyoto 606-8501, Japan

[5] Graduate School of Sports and Health Sciences, Meio University, 1220-1 Biimata, Nago, Okinawa, 905-8585, Japan

**Number of Figures:** 1

**Number of Tables:** 2

**Running Title:** Acceptable walking time and walking behavior

**Authors' Email Addresses:**

Y.K.: y.kamiya@meio-u.ac.jp, A.K.*: akyan@cs.u-ryukyu.ac.jp, M.T.: m.takakura@meio-u.ac.jp

**Abstract**

Walking for transportation is influenced by multiple determinants, including psychological perceptions and environmental factors. Acceptable walking time indicates the maximum time (in min) a person would walk to reach a destination, and is a psychological factor whose association with walking behavior remains insufficiently examined. Therefore, this study clarified the relationship between acceptable walking time and actual walking behavior in the Japanese working-age population, hypothesizing a positive linear association. A cross-sectional online survey of 881 persons (males, $n$ = 310; females, $n$ = 571; age: 20–59 years) in Japan was conducted to analyze acceptable walking time. Participants indicated "What distance (min) would you walk to a destination?" with responses categorized into six groups (≤2 to ≥21 min). Weekly walking time was measured using the International Physical Activity Questionnaire–short form. Linear and quadratic trends were assessed using regression analysis with orthogonal polynomial contrast, adjusted for age and stratified by sex and residential location (Greater Tokyo vs rural Okinawa). Weekly walking duration showed significant positive linear associations with acceptable walking time across all four demographic groups, with some evidence of quadratic components in males after adjusting for age. These consistent positive associations were observed across both residential locations for both sexes, with predominantly linear patterns. This study confirmed a positive association between acceptable walking time and actual walking behavior in the Japanese working-age population, with

consistent patterns across sex and locations. Acceptable walking time may serve as a useful psychological indicator of walking behavior.

**Keywords:** physical activity, walking for transportation, acceptable walking distance, walking time

**Title:** Acceptable walking time は日本人の働く世代における歩行行動の指標：横断研究

**Authors:** 神谷 義人 [1,2], 喜屋武 享 [3,4*], 高倉 実 [5]

**Institutions:**

[1] 名桜大学人間健康学部スポーツ健康学科、〒905-8585 沖縄県名護市為又 1220-1

[2] 琉球大学大学院保健学研究科、〒901-2720 沖縄県宜野湾市字喜友名 1076 番地　A 棟 07-1100

[3] 琉球大学医学部保健学科、〒901-2720 沖縄県宜野湾市字喜友名 1076 番地　A 棟 07-1100

[4] 京都大学大学院医学研究科、〒606-8501 京都市左京区吉田近衛町

[5] 名桜大学大学院スポーツ健康学研究科、〒905-8585 沖縄県名護市為又 1220-1

Abstract

身体活動の重要な構成要素である移動のための歩行は、心理的・環境的要因に影響される。Acceptable walking time (AWT)は、何分までの距離であれば歩行を選択するかを評価する指標であり、歩行行動との関連性が十分検討されていない心理的要因である。本研究では、日本人の働く世代における AWT と実際の歩行行動の関係を検討し、正の線形関連を示すか検証した。日本人 881 名（男性 310 名、女性 571 名、20-59 歳）を対象とし、横断的オンライン調査を実施した。参加者は「目的地までどのくらいの距離（分）であれば歩行するか」に回答し、6 群（≤2 分から ≥21 分）に分類した。週間歩行時間を IPAQ 短縮版で評価し、年齢調整後、性別と居住地（首都圏対沖縄地方）で層別化した直交多項式回帰で線形・二次トレンドを検討した。全 4 つのグループにおいて AWT と週間歩行時間に有意な正の線形関連を認め、男性グループでは年齢調整後に二次トレンドもみられた。これらの一貫した正の関連は両居住地において男女ともに観察され、主に線形パターンを示した。本研究により、日本人の働く世代において AWT と実際の歩行行動の正の関連が性別・地域を超えて一貫したパターンを示すことが確認され、AWT は歩行行動の有用な指標となりうることが示唆された。

Keywords: physical activity, walking for transportation, acceptable walking distance, walking time

## 1. Introduction

The World Health Organization published a Global Action Plan on Physical Activity 2018–2030, with the goals of reducing physical inactivity by 10% and 15% by 2025 and 2030, respectively.[1] However, the prevalence of physical inactivity among adults is increasing, particularly in high-income countries.[2,3] The respective rates of participation in physical activity are low in Japan, with only 24% and 17% of adult males and females, respectively, aged 20–64 years meeting the recommended levels.[4]

Owing to technological advancements driving increased mechanization and automation, coupled with the proliferation of sedentary occupations,[5] walking for transportation has emerged as a promising strategy to enhance physical activity levels among working-age populations.[6,7] The determinants of transportation walking, a primary component of active travel,[8,9] have been investigated through various ecological frameworks.[10] Evidence has indicated that walking for transportation varies according to sociodemographic characteristics.[7,11] Additionally, built environment factors, particularly accessibility to public transportation infrastructure, demonstrate substantial associations with transportation walking behaviors.[12,13]

Various psychological factors have been studied in relation to walking for transportation, with scattered references focusing on acceptable walking distance or acceptable walking time (AWD/AWT). This construct represents individuals' subjective threshold regarding how much

time they are willing to walk to reach a destination. AWD originated in urban and transportation planning domains, initially conceptualized by Seneviratne[14] as the "critical walking distance," and subsequently developed by Arasan et al.[15] as the maximum trip length that pedestrians would traverse before selecting a faster mode of travel, mathematically derived from cumulative distribution curves. Public health researchers subsequently introduced subjective measures such as "reasonable walking distance"[16,17] and "easy walking distance,"[18] assessed through direct inquiry methodologies. Although various studies have attempted to use AWD/AWT, these efforts remain fragmented, with no systematic movement toward standardizing the AWD/AWT index. Nevertheless, due to its high versatility in assessing psychological factors related to walking behavior, this metric is now widely applied across multiple disciplines, including public health, urban planning, and transportation planning.[19-24] In most AWD/AWT studies, it is treated as an outcome variable, with sociodemographic and environmental factors examined as determinants. Pongprasert and Kubota[19] demonstrated that AWD varies by social class among Transit-Oriented Development residents in Bangkok, Thailand. Rahul and Verma[20] and Tsunoda et al.[23] reported that acceptable walking and cycling distances differ according to sociodemographic and regional factors, suggesting potential environmental influences on AWD. Hoang-Tung et al.[21] investigated the impact of Bus Rapid Transit (BRT) implementation in Hanoi, Vietnam, and reported that commuters' AWD increased from <500 m to >500 m following BRT introduction, exemplifying how

infrastructure development can transform AWD thresholds.

The limited extant literature suggests a positive correlation between AWD and actual pedestrian behavior. Hsia et al.[25] demonstrated that individuals with higher AWD report greater actual walking distances, indicating that attitudinal modifications may precipitate behavioral changes. Adults in the United States who perceived longer distances as reasonable walked significantly more often than those who did not.[17] Although a positive association between AWD and walking behavior has been suggested, few investigations and methodological inconsistencies exist in the literature. However, empirical evidence remains sparse, with studies either assuming behavioral intention without examining actual behavior[19] or lacking clarity in the AWD/AWT concept itself.[23,26] Here, we adopted an AWT over AWD for its greater generalizability.[19,24] Furthermore, time-based measures are more intuitive and practical for respondents, as people typically think in terms of how long it takes to walk to destinations (e.g., public transportation stops) rather than specific distances,[27] and time is easier for individuals to estimate accurately than travel distance.[28] While previous studies have suggested associations between AWD and health outcomes, the direct relationship between AWT and walking behavior remains unestablished. This limits our understanding of AWT as a behavioral construct and its potential applications as an assessment tool or intervention target. Establishing this relationship using self-reported measures would provide a rationale for future validation using objective measures (e.g., accelerometry). AWT may serve as a valuable predictive

58 indicator of physical activity because it captures individuals' behavioral intention and
59 motivation to engage in walking behavior. Additionally, the relationship between AWT and
60 walking behavior may vary across different demographic and geographic contexts. Previous
61 research has indicated that walking patterns differ significantly between sexes due to variations
62 in travel purposes, safety concerns, and mobility preferences.[6,29] Similarly, urban infrastructure
63 and walkability characteristics substantially influence walking behavior,[30,31] with metropolitan
64 and rural areas presenting distinct environmental contexts for pedestrian activity.[12,13] Whether
65 AWT maintains consistent predictive validity across these diverse demographic and
66 geographic contexts remains unexplored. Therefore, we clarified the relationship between
67 AWT and self-reported walking behavior in the Japanese working-age population, with
68 analyses stratified by sex and residential location. We hypothesized that individuals with longer
69 AWTs would walk more often than those with shorter AWTs, indicating a positive linear
70 relationship.
71
72 **2. Materials and Methods**
73 2.1. Participants
74 We conducted an online survey through Macromill Inc. (Tokyo, Japan) of 800 adult males
75 and females aged 20–59 years residing in Greater Tokyo (Tokyo, Saitama, Chiba, and
76 Kanagawa prefectures) and a rural area (Okinawa Prefecture) of Japan during November 2021.

77 The study included the working-age population with diverse employment statuses, including
78 employed individuals, unemployed individuals, and students. While Okinawa Prefecture
79 includes urban and rural characteristics, it is classified as rural relative to the Greater Tokyo
80 area based on its population density (643 vs 2,721 people/km² for Greater Tokyo, according to
81 the 2020 National Census of Japan[32]), geographic isolation as an island prefecture, distance
82 from major economic centers, and fundamentally different transportation characteristics.
83 Greater Tokyo exemplifies a public transit-oriented environment with extensive rail networks,
84 whereas Okinawa represents a car-dependent region, with private vehicle modal shares
85 exceeding 90%.[33] This contrasting sampling design enables the examination of AWT–walking
86 relationships across Japan's transportation modal spectrum.
87 The sample size was calculated using power analysis (effect size = 0.15, $\alpha = 0.05$, power =
88 0.80) stratified by sex and age decades. The survey was terminated when the number of
89 respondents reached the target number. Survey invitations were sent to approximately 5,000
90 registered monitors, who received requests for participation and an online response form.
91 Exclusion criteria included individuals with physical disabilities that made walking difficult
92 and pregnant females. Among 885 respondents, 881 were selected for analysis, excluding one
93 person whose sex was recorded as “other” and three people with missing household income
94 data. Respondents were given Macromill points (40 yen), which could be exchanged for
95 specific services from Macromill Inc.

96 Personal information was protected by a contract between registered participants and
97 Macromill Inc. (Tokyo, Japan). We did not have access to personal information about the
98 participants. All procedures were conducted in accordance with the ethical standards of the
99 national research committee and Helsinki Declaration. This study was approved by ethics
100 review committees (approval numbers: 1819 and 2021-035-1), and electronic informed consent
101 was obtained from all participants.

102 2.2 Variables

103 2.2.1 Walking behavior

104 The International Physical Activity Questionnaire-Short Form (IPAQ-SF) is a self-report
105 instrument that measures the weekly frequency and duration of walking, as well as low-
106 intensity, moderate-intensity, and high-intensity physical activities.[34] We targeted only walking
107 among the four activity types.

108 The survey investigated the amount of time spent walking continuously for at least 10 min,
109 including walking to transportation facilities, for exercise, and for leisure. Data were processed
110 according to IPAQ-SF guidelines.[35]

111 2.2.2 Acceptable walking time

112 AWT was evaluated with reference to Tsunoda et al.'s study.[23] The question used was, "What
113 distance (in minutes) would you walk to a destination (e.g., convenience store, supermarket,
114 restaurant, bus stop, station, or hospital)? (Imagine it is a pleasant day and the road is flat)."

115 Respondents had to select from the following: ≤1, 2, 5, 10, 15, 20, 30, or >31 min. As 21 (2.4%)
116 and 36 (4.1%) of the respondents selected the options of ≤1 and >31 min, respectively, we
117 analyzed data from those who would walk for ≤2, 3–5, 6–10, 11–15, 16–20, and ≥21 min.
118 2.2.3 Sociodemographic factors
119 Sociodemographic factors included sex (male/female), age, residential location
120 (metropolitan or rural), marital status (married or not), employment (yes or no), education level
121 (junior/high school, college, university, post-graduate school, or unknown), and annual
122 household income (<2, ≥2 to <6, ≥6 million yen, or unknown) as previously described.[17]
123 2.3 Statistical analysis
124 All analyses were stratified by sex and residential location (metropolitan vs rural), based on
125 previous literature. Differences in characteristics between sexes were assessed using chi-square
126 tests and *t*-tests for categorical and continuous variables, respectively. Linear and quadratic
127 trends in AWT and the amount of time spent walking per week were assessed using linear
128 regression analysis with orthogonal polynomial contrasts.[17] Weekly walking time data were
129 natural log-transformed due to their non-normal distribution. To manage zero values in the
130 walking time data, one was added to all values before log transformation (log[x+1]
131 transformation). Results are presented as log-transformed values, and trends were adjusted for
132 age. All values with $p < 0.05$ were considered significant, and all data were statistically analyzed
133 using SPSS (version 25.0J for Windows; SPSS Japan Inc., Tokyo, Japan).

## 3. Results

Table 1 lists the demographic factors and AWT by sex. Among males, the most frequent AWT categories were 6–10 (29.0%), 3–5 (25.5%), and 11–15 min (18.7%). The distribution of AWT responses approximated a normal distribution with a peak at 6–10 min. For females, the most frequent AWT categories were also 6–10 (26.3%), 3–5 (22.9%), and 11–15 min (18.6%). The cumulative total was ≤10 min, accounting for 63.5% and 56.7% of males and females, respectively, and the overall distribution of AWT significantly differed between sexes across all demographic factors.

AWT was significantly associated with residential location for both sexes (male, $p = 0.003$; female, $p < 0.001$) and with household income (male, $p = 0.014$; female, $p = 0.008$; Table 2). In the Tokyo metropolitan area, 27.3% of males and 14.8% of females reported an AWT of 3–5 min, whereas in the rural area, these proportions were significantly higher at 43.4% and 44.4%, respectively. A significant linear relationship was observed between AWT categories (from ≤2 to ≥21 min) and weekly walking duration for both sexes ($p < 0.001$).

Figure 1 displays the relationship between AWT and weekly walking duration by sex and residential location. Analysis of log-transformed weekly walking time data revealed significant linear associations between AWT categories and walking duration across all examined demographic groups. Linear trends were consistently significant ($p < 0.001$), with some

153 evidence of quadratic components in certain groups, although the predominant pattern
154 remained linear. When stratified by sex and residential location, consistent positive
155 associations were observed between AWT and walking behavior, even after adjusting for
156 covariates. The relationship between AWT and walking behavior showed consistent patterns
157 across both metropolitan and rural residential locations.
158
159 **4. Discussion**
160 This study revealed a positive linear relationship between AWT and walking duration in both
161 sexes and across residential locations, supporting our hypothesis. When stratified by sex and
162 residential location, significant linear associations were consistently observed between the
163 AWT categories and log-transformed weekly walking time, indicating that individuals with
164 longer AWT exhibited greater walking behavior among the Japanese working-age population.
165 The observed linear association suggests that AWT represents a psychological factor associated
166 with walking behavior. These findings align with those of previous studies showing positive
167 associations between AWT and walking behavior,[17] suggesting that our results contribute to a
168 consistent pattern across various populations and methodological approaches. Our finding that
169 82.3% of males and 75.3% of females consider ≤15 min acceptable provide insight into
170 Japanese adults' walking thresholds, although practical implications require further
171 investigation using objective measures and longitudinal designs. The observed sex differences

172 in AWT distribution patterns may have important implications for health promotion strategies.
173 Although both sexes showed significant positive associations between AWT and walking
174 behavior, with predominantly linear patterns, the underlying factors driving these relationships
175 may differ between males and females. Previous research has suggested that walking behavior
176 is influenced by sex-specific factors, including safety perceptions, trip purposes, and social
177 roles. However, considering that both sexes demonstrated similar linear trends in this study,
178 the practical implications of these differences warrant careful consideration. Future research
179 should examine the specific factors contributing to sex differences in AWT to inform sex-
180 responsive health promotion approaches that support walking behavior across diverse
181 populations.

182 Future research should examine the function of AWT within established theoretical
183 frameworks. The COM-B model[36,37] suggests that AWT may serve as a motivational
184 component mediating the relationships between individual capabilities (age and physical
185 capacity), environmental opportunities (urban infrastructure and transportation accessibility),
186 and walking behavior. Our observation of regional differences in AWT distribution between
187 Greater Tokyo and rural areas supports the premise that environmental factors influence
188 motivational constructs. Recent COM-B applications to physical activity[38] and sedentary
189 behavior[39] identified the following key predictors: habits and exercise self-identity
190 (motivation), self-monitoring (capability), and subjective norms (opportunity).[40] These

191 findings provide a framework for investigating how AWT functions as a motivational factor
192 and interacts with environmental and individual factors. Although previous studies
193 conceptualized AWD as behavioral intention,[19] comprehensive COM-B framework studies
194 incorporating environmental factors are needed to elucidate the complete psychological
195 mechanisms of AWT in walking behavior.

196 While this study demonstrated the relationship of AWT with self-reported walking behavior,
197 the IPAQ-SF overestimates activity by 150–400% compared with that of objective
198 measurements.[35] Future research using accelerometry is essential to validate the AWT–walking
199 behavior relationship and determine whether specific AWT thresholds predict meeting physical
200 activity recommendations. Additionally, since walking purposes influence acceptable
201 distances,[14,15,24] future studies should evaluate the relationship of AWT specifically with
202 walking for transportation rather than general walking behavior.

203 The present study showed that an AWT of 6–10 min (29.0% of males and 26.3% of females)
204 had the highest frequency among both sexes, and that more than half of the adults engaged in
205 AWT for <10 min. The average time spent walking (11.9 min) varies between 10 and 15 min
206 depending on the purpose, such as commuting to work, shopping, or engaging in social or
207 recreational activities.[41] These results were generally consistent, although they were slightly
208 higher than that of our findings on AWT among Japanese adults. The concepts of the "15-min
209 city"[42] or "20-min neighborhood"[43] have gained traction in recent urban planning. These

210 frameworks enhance urban sustainability by decentralizing city functions and ensuring that
211 daily necessities are accessible within a 15-min walk or bicycle ride. The traditional concept
212 of "walking distance" in Japan is typically a 10-min walk, approximately 800 m,[44] based on an
213 average walking speed of 80 m/min.[45] Our findings indicated that 17.7% and 24.7% of males
214 and females, respectively, consider walking to destinations for >15 min acceptable. While these
215 findings provide useful context for urban planning concepts, such as the 15-min city, extensive
216 validation through longitudinal and objective measurement studies is required before practical
217 applications can be considered. If future research establishes causal relationships and validates
218 the behavioral relevance of AWT through objective measures, AWT data may eventually
219 contribute to evidence-based planning approaches, potentially informing facility distribution
220 decisions that align with residents' psychological walking thresholds.[20] The sex-specific
221 patterns identified herein may provide evidence-based guidelines for prioritizing pedestrian
222 infrastructure improvements.[15] Furthermore, the association between AWT and actual walking
223 behavior represents a potential foundation for future intervention research, although extensive
224 longitudinal studies using objective measures are essential to establish causality before any
225 practical applications. Following comprehensive validation, the AWT index may eventually
226 serve as a tool for measuring walking motivation, potentially providing insights into residents'
227 walking preferences and thresholds.
228 Once causal relationships are established through rigorous longitudinal research with

objective measures, insights into AWT might inform urban design approaches to accommodate and encourage walking. However, substantial additional research would be needed to establish whether and how AWT insights could translate into effective planning strategies. The consistency of AWT–walking behavior relationships observed across Tokyo's transit-oriented environment and Okinawa's car-dependent setting[32,33] suggests that AWT functions as a stable psychological construct that transcends specific transportation contexts. This consistency represents a promising foundation for future research. However, extensive validation would be required before considering the scalability of AWT-based approaches across Japan's diverse geographic and infrastructural landscapes.

This study had limitations. The cross-sectional design precluded the exploration of causal relationships between AWT and walking behavior. Walking data were self-reported using the IPAQ-SF, overestimating activity compared with that of objective measures. We adjusted for only basic demographic factors (age and sex) and residential location in our analyses. Future studies should consider socioeconomic factors and transportation-related variables, such as driver's license possession and car use. The online survey methodology introduced potential sampling bias, as internet users tend to be younger, more educated, and have higher incomes,[46] potentially affect generalizability. However, our findings align with those of previous studies,[17,25] suggesting positive AWD/AWT–walking behavior associations, suggesting the observed relationship may be robust across different populations and methodological

248 approaches.

249

250 **5. Conclusions**

251 This study confirmed a positive association between AWT and actual walking behavior in the
252 Japanese working-age population. Therefore, AWT may be useful as an indicator of walking
253 behavior.

254

255 **Ethical approval**

256 This research proposal was reviewed and approved by the Ethics Review Committee for Life
257 Science and Medical Research Involving Human Subjects at the University of the Ryukyus
258 (approval number: 1819) and by the University Research Ethics Committee at Meio University
259 (approval number: 2021-035-1). Informed consent was obtained from all participants before
260 their inclusion in the study. All procedures were conducted in accordance with the ethical
261 standards of the national research committee and the Helsinki Declaration.

262

263 **Competing interests/Conflicts of interest**

264 The authors declare that there are no conflicts of interest.

265

266 **Acknowledgments**

The authors thank the participants for their cooperation in the study. The work was supported by a grant from the President's Discretionary Fund of Meio University. We would also like to thank Editage (www.editage.com) for English language editing.

## Contributions

YK: Conceptualization, Investigation, Formal Analysis, and Writing – Original Draft. AK: Writing – Review and Editing. MT: Supervision and Writing – Review and Editing.

## References


1) World Health Organization. 2018. *Global Action Plan on Physical Activity 2018–2030: More Active People for a Healthier World: at-a-Glance*. Geneva, Switzerland.

2) Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN and Katzmarzyk PT. 2012. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of the burden of disease and life expectancy. *Lancet* 380: 219–229. doi: 10.1016/S0140-6736(12)61031-9.

3) Guthold R, Stevens GA, Riley LM and Bull FC. 2018. Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants. *Lancet Glob Health*. 6: e1077–e1086. doi: 10.1016/S2214-109X(18)30357-7.

4) Ministry of Health, Labor, and Welfare of Japan. 2019. National health and nutrition survey. Available from: https://www.mhlw.go.jp/content/10900000/000687163.pdf [accessed February 28, 2025].

5) Church TS, Thomas DM, Tudor-Locke C, Katzmarzyk PT, Earnest CP, Rodarte RQ, Martin CK, Blair SN and Bouchard C. 2011. Trends over 5 decades in U.S. occupation-related physical activity and their associations with obesity. *PLOS One* 6: e19657. doi: 10.1371/journal.pone.0019657.

6) Pollard TM and Wagnild JM. 2017. Gender differences in walking (for leisure, transport

and in total) across adult life: a systematic review. *BMC Public Health* 17: 341. doi: 10.1186/s12889-017-4253-4.

7) Adjaye-Gbewonyo D and Briones EM. 2024. *Walking for Leisure and Transportation Among Adults: United States, 2022*. USA Centers for Disease Control and Prevention, Atlanta, GA.

8) Cook S, Stevenson L, Aldred R, Kendall M and Cohen T. 2022. More than walking and cycling: what is 'active travel'? *Transport Policy* 126: 151–161. doi: 10.1016/j.tranpol.2022.07.015.

9) Ding D, Luo M, Infante MFP, Gunn L, Salvo D, Zapata-Diomedi B, Smith B, Bellew W, Bauman A, Nau T and Nguyen B. 2024. The co-benefits of active travel interventions beyond physical activity: a systematic review. *Lancet Planet Health* 8: e790–e803. doi: 10.1016/S2542-5196(24)00201-8.

10) Sallis JF and Owen N. 2015. Ecological models of health behavior. In: *Health Behavior Theory Research and Practice* (Glanz K, Rimer BK, Viswanath K, eds.). 43–64, Jossey-Bass, San Francisco, CA, USA.

11) Lee C and Moudon AV. 2006. Correlates of walking for transportation or recreation purposes. *J Phys Act Health* 3: S77–S98. doi: 10.1123/jpah.3.s1.s77.

12) Sallis JF, Cerin E, Conway TL, Adams MA, Frank LD, Pratt M, Salvo D, Schipperijn J, Smith G, Cain KL, Davey R, Kerr J, Lai PC, Mitáš J, Reis R, Sarmiento OL, Schofield G,

315 Troelsen J and Van Dyck D, et al. 2016. Physical activity in relation to urban environments
316 in 14 cities worldwide: a cross-sectional study. *Lancet* 387: 2207–2217. doi:
317 10.1016/S0140-6736(15)01284-2.
318 13) Sugiyama T, Neuhaus M, Cole R, Giles-Corti B and Owen N. 2012. Destination and route
319 attributes associated with adults' walking: a review. *Med Sci Sports Exerc* 44: 1275–1286.
320 doi: 10.1249/MSS.0b013e318247d286.
321 14) Seneviratne PN. 1985. Acceptable walking distances in central areas. *J Transp Eng* 111:
322 365–376. doi: 10.1061/(ASCE)0733-947X(1985)111:4(365).
323 15) Arasan VT, Rengaraju VR and Rao KVK. 1994. Characteristics of trips by foot and bicycle
324 modes in Indian city. *J Transp Eng* 120: 283–294. doi: 10.1061/(ASCE)0733-
325 947X(1994)120:2(283).
326 16) Rafferty AP, McGee HB, Petersmarck KA and Miller CE. 2004. Proportion of trips made
327 by walking: estimating a state-level baseline for Healthy People 2010 Objective 22–14.
328 *Am J Health Promot* 18: 387–391. doi: 10.4278/0890-1171-18.5.387.
329 17) Watson KB, Carlson SA, Humbert-Rico T, Carroll DD and Fulton JE. 2015. Walking for
330 transportation: what do U.S. adults think is a reasonable distance and time? *J Phys Act*
331 *Health* 12: S53–S61. doi: 10.1123/jpah.2014-0062.
332 18) Colabianchi N, Dowda M, Pfeiffer KA, Porter DE, Almeida MJC and Pate RR. 2007.
333 Towards an understanding of salient neighborhood boundaries: adolescent reports of an

334 easy walking distance and convenient driving distance. *Int J Behav Nutr Phys Act* 4: 66.
335 doi: 10.1186/1479-5868-4-66.
336 19) Pongprasert P and Kubota H. TOD residents' attitudes toward walking to transit station: a
337 case study of transit-oriented developments (TODs) in Bangkok, Thailand. *J Mod*
338 *Transport* 27: 39–51. doi: 10.1007/s40534-018-0170-1.
339 20) Rahul TM and Verma A. 2014. A study of acceptable trip distances using walking and
340 cycling in Bangalore. *J Transp Geogr* 38: 106–113. doi: 10.1016/j.jtrangeo.2014.05.011.
341 21) Hoang-Tung N, Kato H, The Huy TT, Le Binh P and Duy L. 2021. Impacts of the
342 introduction of bus rapid transit on travel behaviors of commuters in Hanoi, Vietnam: a
343 quasi-experimental approach. *Case Stud Transp Policy* 9: 95–102. doi:
344 10.1016/j.cstp.2020.10.002.
345 22) Rahul TM, Manoj M, Tahlyan D and Verma A. 2021. The influence of activities and socio-
346 economic/demographic factors on the acceptable distance in an Indian scenario. *Transp*
347 *Dev Econ* 7: 1–13. doi: 10.1007/s40890-020-00110-3.
348 23) Tsunoda K, Soma Y, Kitano N, Jindo T, Fujii K and Okura T. 2021. Acceptable walking
349 and cycling distances and their correlates among older Japanese adults. *J Popul Ageing*
350 14: 183–200. doi: 10.1007/s12062-020-09272-9.
351 24) Verma A, Verma M, Rahul TM, Khurana S and Rai A. 2018. Acceptable trip distance for
352 walking in mass religious gatherings—A case study of world's largest human gathering

353 Kumbh Mela in Ujjain, India. *Sustain Cities Soc* 41: 505–512. doi:
354 10.1016/j.scs.2018.06.010.
355 25) Hsia HCH, Yeh KY, Tsukaguchi H and Vandebona U. 2013. The study of the relationships
356 among psychological factors, acceptable walking distance, and reported walking distance
357 for shopping trips. *J East Asia Soc Transp Stud* 10: 1475–1488. doi:
358 10.11175/easts.10.1475.
359 26) Tsunoda K, Nagata K, Jindo T, Fujii Y, Soma Y, Kitano N and Okura T. 2023. Acceptable
360 walking and cycling distances and functional disability and mortality in older Japanese
361 adults: an 8-year follow-up study. *Health Place* 79: 102952. doi:
362 10.1016/j.healthplace.2022.102952.
363 27) Tennøy A, Knapskog M and Wolday F. 2022. Walking distances to public transport in
364 smaller and larger Norwegian cities. *Transp Res D Transp Environ* 103: 103169. doi:
365 10.1016/j.trd.2022.103169.
366 28) Van Soest D, Tight MR and Rogers CD. 2020. Exploring the distances people walk to
367 access public transport. *Transp Rev* 40: 160–182. doi: 10.1080/01441647.2020.1712494.
368 29) Amagasa S, Inoue S, Shibata A, Ishii K, Kurosawa S, Owen N and Oka K. 2022.
369 Differences in accelerometer-measured physical activity and sedentary behavior between
370 middle-aged men and women in Japan: a compositional data analysis. *J Phys Act Health*
371 19: 500–508. doi: 10.1123/jpah.2022-0098.

30) Saelens BE and Handy SL. 2008. Built environment correlates of walking: a review. *Med Sci Sports Exerc* 40: S550–S566. doi: 10.1249/MSS.0b013e31817c67a4.

31) Ewing R and Cervero R. 2010. Travel and the built environment: a meta-analysis. *J Am Plann Assoc* 76: 265–294. doi: 10.1080/01944361003766766.

32) Ministry of Internal Affairs and Communications, Statistics Bureau of Japan. 2020. 2020 population census of Japan. e-Stat. Available from: https://www.e-stat.go.jp/stat-search/database?page=1&toukei=00200521 [accessed July 16, 2025].

33) Ministry of Internal Affairs and Communications, Statistics Bureau of Japan. 2020. Population estimates (Reiwa 2). e-Stat. Available from: https://www.e-stat.go.jp/stat-search/files?page=1&layout=datalist&toukei=00200521&tstat=000001136464&cycle=0&year=20200&month=24101210&tclass1=000001136469 [accessed July 16, 2025].

34) Lee PH, Macfarlane DJ, Lam TH and Stewart SM. 2011. Validity of the international physical activity questionnaire short form (IPAQ-SF): a systematic review. *Int J Behav Nutr Phys Act* 8: 115. doi: 10.1186/1479-5868-8-115.

35) Forde C. 2018. Scoring the International Physical Activity Questionnaire (IPAQ). Available from: https://ugc.futurelearn.com/uploads/files/bc/c5/bcc53b14-ec1e-4d90-88e3-1568682f32ae/IPAQ_PDF.pdf [accessed March 1, 2025].

36) Michie S, Van Stralen MM and West R. 2011. The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implement Sci* 6:42. doi:

391 10.1186/1748-5908-6-42.

392 37) Kim J, Mizushima R, Nishida K, Morimoto M and Nakata Y. 2022. Proposal of a
393 comprehensive and multi-component approach to promote physical activity among
394 Japanese office workers: a qualitative focus group interview study. *Int J Environ Res*
395 *Public Health* 19: 2172. doi: 10.3390/ijerph19042172.

396 38) Howlett N, Schulz J, Trivedi D, Troop N and Chater A. 2019. A prospective study
397 exploring the construct and predictive validity of the COM-B model for physical activity.
398 *J Health Psychol* 24: 1378–1391. doi: 10.1177/1359105317739098.

399 39) Howlett N, Schulz J, Trivedi D, Troop N and Chater A. 2021. Determinants of weekly
400 sitting time: construct validation of an initial COM-B model and comparison of its
401 predictive validity with the theory of planned behaviour. *Psychol Health* 36: 96–114. doi:
402 10.1080/08870446.2020.1763994.

403 40) Van Kasteren YF, Lewis LK and Maeder A. 2020. Office-based physical activity: mapping
404 a social ecological model approach against COM-B. *BMC Public Health* 20:163. doi:
405 10.1186/s12889-020-8280-1.

406 41) Watson KB, Whitfield GP, Bricka S and Carlson SA. 2021. Purpose-based walking trips
407 by duration, distance, and select characteristics, 2017 National Household Travel Survey.
408 *J Phys Act Health* 18: 86–93.

409 42) Moreno C, Allam Z, Chabaud D, Gall C and Pratlong F. 2021. Introducing the "15-minute

City": sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities* 4: 93–111. doi: 10.3390/smartcities4010006.

43) Mackness K, White I and Barrett P. 2023. 20-Minute neighborhoods: opportunities and challenges. In: *Handbook of Sustainability Science in the Future: Policies, Technologies and Education by 2050*. 1–22, Springer, Princeton, NJ, USA. doi: 10.1007/978-3-031-04560-8_172.

44) Ministry of Land, Infrastructure, Transport and Tourism, Urban Planning Division, City Bureau. Handbook on the evaluation of urban structure. 2014. Available from: https://www.mlit.go.jp/common/001104012.pdf [accessed March 7, 2025].

45) Real Estate Fair Trade Council Federation. 2019. Enforcement rules for fair competition regulations concerning real estate representation. Available from: https://www.rftc.jp/webkanri/kanri/wp-content/uploads/2019/02/h_sekoukisoku.pdf [accessed March 7, 2025].

46) Rhodes SD, Bowie DA and Hergenrather KC. 2003. Collecting behavioural data using the World Wide Web: considerations for researchers. *J Epidemiol Community Health* 57: 68–73. doi: 10.1136/jech.57.1.68.

427 **Tables**

Table 1. Demographic characteristics, walking, and acceptable walking time

| | Males | | Females | | |
|---|---|---|---|---|---|
| | N = 310 | | N = 571 | | *p* [a] |
| Age (years), mean (SD) | 43.6 | (11.5) | 35.5 | (10.2) | <.001 |
| Residential area, % | | | | | |
| Greater Tokyo | 172 | (55.5) | 269 | (47.1) | .018 |
| rural area | 138 | (44.5) | 302 | (52.9) | |
| Marital status, % | | | | | |
| Unmarried | 114 | (36.8) | 256 | (44.8) | .021 |
| Married | 196 | (63.2) | 315 | (55.2) | |
| Employment status, % | | | | | |
| Employed | 265 | (85.5) | 272 | (47.6) | <.001 |
| Not employed | 45 | (14.5) | 299 | (52.4) | |
| Education level, % | | | | | |
| ≤ High school graduate | 84 | (27.1) | 173 | (30.3) | <.001 |
| Some college | 61 | (19.7) | 174 | (30.5) | |
| ≥ College graduate | 165 | (53.2) | 223 | (39.1) | |
| Other | 0 | (0) | 1 | (0.2) | |
| Household income, % | | | | | |
| <￥2,000,000 | 22 | (7.1) | 71 | (12.4) | <.001 |
| ￥2,000,000–6,000,000 | 120 | (38.7) | 266 | (46.6) | |
| ≥￥6,000,000 | 127 | (41.0) | 149 | (26.1) | |
| Unknown | 41 | (13.2) | 85 | (14.9) | |
| BMI (kg/m$^2$), mean (SD) | 23.5 | (3.4) | 21.3 | (3.7) | <.001 |
| Walking duration (min/week), median (range) | 180 | (0–379) | 120 | (0–300) | .014 |
| Acceptable walking time | | | | | |
| ≤2 min | 28 | (9.0) | 43 | (7.5) | .191 |
| 3–5 min | 79 | (25.5) | 131 | (22.9) | |
| 6–10 min | 90 | (29.0) | 150 | (26.3) | |
| 11–15 min | 58 | (18.7) | 106 | (18.6) | |
| 16–20 min | 23 | (7.4) | 73 | (12.8) | |
| ≥21 min | 32 | (10.3) | 68 | (11.9) | |

[a] Chi-square tests for categorical variables and t-tests for continuous variables were applied.

Abbreviations: BMI, body mass index; SD, standard deviation

428

Table 2. Acceptable walking time by demographic characteristic

| | Acceptable walking time | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤2 min | | 3–5 min | | 6–10 min | | 11–15 min | | 16–20 min | | ≥21 min | | *p* [a] | *p* for trend [b] |
| Male sex, % | 28 | (9.0) | 79 | (25.5) | 90 | (29.0) | 58 | (18.7) | 23 | (7.4) | 32 | (10.3) | | |
| Age (years), mean (SD) | 40.0 | (10.8) | 41.9 | (12.1) | 44.4 | (11.1) | 43.1 | (12.2) | 50.8 | (8.7) | 44.5 | (9.9) | .014 | |
| Residential area, % | | | | | | | | | | | | | | |
| Greater Tokyo | 10 | (5.8) | 37 | (21.5) | 47 | (27.3) | 36 | (20.9) | 18 | (10.5) | 24 | (14.0) | .003 | |
| rural area | 18 | (13.0) | 42 | (30.4) | 43 | (31.2) | 22 | (15.9) | 5 | (3.6) | 8 | (5.8) | | |
| Marital status, % | | | | | | | | | | | | | | |
| Unmarried | 10 | (8.8) | 30 | (26.3) | 32 | (28.1) | 24 | (21.1) | 7 | (6.1) | 11 | (9.6) | .952 | |
| Married | 18 | (9.2) | 49 | (25.0) | 58 | (29.6) | 34 | (17.3) | 16 | (8.2) | 21 | (10.7) | | |
| Employment status, % | | | | | | | | | | | | | | |
| Employed | 23 | (8.7) | 67 | (25.3) | 77 | (29.1) | 48 | (18.1) | 21 | (7.9) | 29 | (10.9) | .858 | |
| Not employed | 5 | (11.1) | 12 | (26.7) | 13 | (28.9) | 10 | (22.2) | 2 | (4.4) | 3 | (6.7) | | |
| Education level, % | | | | | | | | | | | | | | |
| ≤ High school graduate | 7 | (9.7) | 27 | (27.6) | 28 | (29.6) | 14 | (13.6) | 3 | (8.6) | 5 | (10.9) | .063 | |
| Some college | 8 | (8.1) | 17 | (26.3) | 20 | (30.5) | 9 | (18.6) | 5 | (9.3) | 2 | (7.2) | | |
| ≥ College graduate | 13 | (6.9) | 35 | (19.9) | 42 | (23.5) | 35 | (22.0) | 15 | (13.3) | 25 | (14.3) | | |
| Other | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | | | |
| Household income, % | | | | | | | | | | | | | | |
| <￥2,000,000 | 6 | (27.3) | 7 | (31.8) | 4 | (18.2) | 2 | (9.1) | 2 | (9.1) | 1 | (4.5) | .014 | |
| ￥2,000,000–6,000,000 | 13 | (10.8) | 33 | (27.5) | 41 | (34.2) | 17 | (14.2) | 5 | (4.2) | 11 | (9.2) | | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ≥￥6,000,000 | 8 | (6.3) | 32 | (25.2) | 29 | (22.8) | 32 | (25.2) | 13 | (10.2) | 13 | (10.2) | | |
| Unknown | 1 | (2.4) | 7 | (17.1) | 16 | (39.0) | 7 | (17.1) | 3 | (7.3) | 7 | (17.1) | | |
| BMI (kg/m$^2$), mean (SD) | 23.3 | (3.9) | 23.6 | (3.3) | 23.6 | (3.3) | 23.7 | (3.5) | 22.7 | (2.9) | 23.4 | (3.4) | .898 | |
| Walking duration (min/week), median (range) | 0 | (0–30) | 120 | (0–300) | 180 | (23–360) | 225 | (80–420) | 360 | (288–420) | 300 | (98–420) | | <.001 |
| Female sex, % | 43 | (7.5) | 131 | (22.9) | 150 | (26.3) | 106 | (18.6) | 73 | (12.8) | 68 | (11.9) | | |
| Age (years), mean (SD) | 32.8 | (9.5) | 36.7 | (9.6) | 36.1 | (10.6) | 35.0 | (10.0) | 33.1 | (10.0) | 37.1 | (11.2) | .052 | |
| Residential area, % | | | | | | | | | | | | | | |
| Greater Tokyo | 9 | (3.3) | 31 | (11.5) | 59 | (21.9) | 65 | (24.2) | 55 | (20.4) | 50 | (18.6) | <.001 | |
| rural area | 34 | (11.3) | 100 | (33.1) | 91 | (30.1) | 41 | (13.6) | 18 | (6.0) | 18 | (6.0) | | |
| Marital status, % | | | | | | | | | | | | | | |
| Unmarried | 26 | (10.2) | 54 | (21.1) | 61 | (23.8) | 48 | (18.8) | 32 | (12.5) | 35 | (13.7) | .203 | |
| Married | 17 | (5.4) | 77 | (24.4) | 89 | (28.3) | 58 | (18.4) | 41 | (13.0) | 33 | (10.5) | | |
| Employment status, % | | | | | | | | | | | | | | |
| Employed | 17 | (6.3) | 68 | (25.0) | 64 | (23.5) | 49 | (18.0) | 36 | (13.2) | 38 | (14.0) | .348 | |
| Not employed | 26 | (8.7) | 63 | (21.1) | 86 | (28.8) | 57 | (19.1) | 37 | (12.4) | 30 | (10.0) | | |
| Education level, % | | | | | | | | | | | | | | |
| ≤ High school graduate | 18 | (10.4) | 44 | (25.4) | 48 | (27.7) | 21 | (12.1) | 19 | (11.0) | 23 | (13.3) | .092 | |
| Some college | 11 | (6.3) | 44 | (25.3) | 52 | (29.9) | 35 | (20.1) | 17 | (9.8) | 15 | (8.6) | | |
| ≥ College graduate | 14 | (6.3) | 43 | (19.3) | 49 | (22.0) | 50 | (22.4) | 37 | (16.6) | 30 | (13.5) | | |
| Other | 0 | (0) | 0 | (0) | 1 | (100) | 0 | (0) | 0 | (0) | 0 | (0) | | |
| Household income, % | | | | | | | | | | | | | | |
| <￥2,000,000 | 4 | (5.6) | 17 | (23.9) | 24 | (33.8) | 13 | (18.3) | 3 | (4.2) | 10 | (14.1) | .008 | |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ￥2,000,000–6,000,000 | 19 | (7.1) | 72 | (27.1) | 66 | (24.8) | 49 | (18.4) | 27 | (10.2) | 33 | (12.4) | | |
| ≥￥6,000,000 | 12 | (8.1) | 26 | (17.4) | 33 | (22.1) | 32 | (21.5) | 34 | (22.8) | 12 | (8.1) | | |
| Unknown | 8 | (9.4) | 16 | (18.8) | 27 | (31.8) | 12 | (14.1) | 9 | (10.6) | 13 | (15.3) | | |
| BMI ($kg/m^2$), mean (SD) | 21.8 | (4.6) | 21.9 | (4.4) | 21.3 | (3.5) | 21.0 | (2.7) | 20.8 | (3.5) | 21.2 | (3.5) | .266 | |
| Walking duration (min/week), median (range) | 0 | (0–90) | 0 | (0–180) | 120 | (0–270) | 150 | (60–278) | 180 | (60–360) | 260 | (120–450) | | <.001 |

[a] Categorical variables were subjected to chi-square, continuous variables to one-way analysis of variance.

[b] The Jonckheere–Terpstra test was used.

Abbreviations: BMI, body mass index; SD, standard deviation

**Figure Legend**

Figure 1. Log-transformed walking minutes per week across sex and residential area groups, adjusted for age. Data points show log-transformed mean values ± standard error. Significant positive linear trends are observed across all groups ($p$ <0.01). Quadratic components are detected in Greater Tokyo ($p$ <0.01) and Okinawa males ($p$ <0.05).

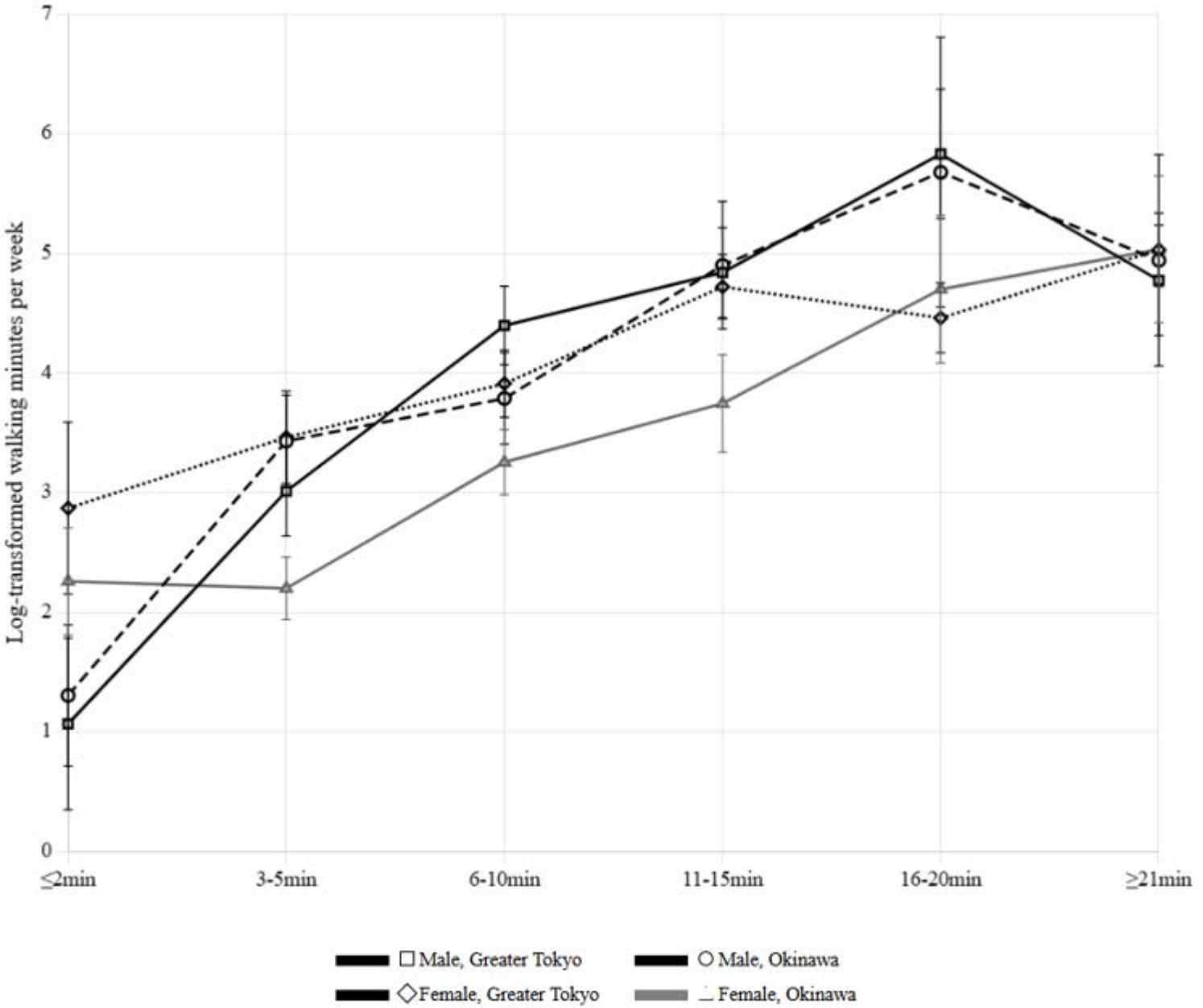


**Figure 1.** Log-transformed walking minutes per week across sex and residence area groups, adjusted for age. Error bars represent standard error. Data points show mean values with 95% confidence intervals.