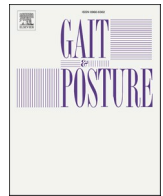




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Change in outdoor walking behavior during the coronavirus disease pandemic in Japan: A longitudinal study

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ABSTRACT

Background: Due to the high infectivity and seriousness of coronavirus disease, people's daily activities were restricted in countries worldwide; governments implemented lockdown measures and advised individuals to perform self-restraint in terms of leaving the house. However, there have been few scientific reports on the effects of such behavioral restrictions on walking parameters.

Research question: Did behavioral restrictions during the state of emergency in Japan effect walking parameters in daily life outdoor walking?

Methods: In this retrospective cohort study, four walking parameters, namely, the average number of steps taken, walking speed, step length, and cadence, were measured using a smartphone application among 3901 participants (mean age \pm standard deviation: 60.3 ± 28.9 years) from March 2 to June 15 in both 2019 and 2020. Repeated-measures two-way analysis of variance was used to compare the walking parameters between the two years.

Results: The number of steps significantly decreased ($p < .001$) in 2020 (~ 3400 steps) compared to that in 2019 (~ 4400 steps), indicating that the state of emergency greatly affected the amount of physical activity performed per individual. Conversely, walking speed increased ($p < .001$ during the period when the state of emergency was issued) in 2020 (~ 1.25 m/s) compared to that in 2019 (~ 1.23 m/s), attributable to an increased step length.

Significance: Although changes in walking speed and step length were small compared to those in the number of steps, those changes were consistently seen during the state of emergency, suggesting that people tried to walk faster in their outdoor walking. Such change in walking behavior may have protected further deterioration of health due to restricted activity.

1. Introduction

Due to the high infectivity and pandemic status of coronavirus disease (COVID-19), people's actions were restricted worldwide, as cities and countries implemented lockdown measures and requested individuals to practice self-restraint. This is the first worldwide pandemic to have occurred after World War II, and it is important to know how these behavioral restrictions affected people's physical activity.

In recent years, portable health-monitoring technology has advanced rapidly, enabling the monitoring of levels of activity such as steps taken per day and heart rate [1,2]. Using such data, service providers have reported on the effects of behavioral restrictions on physical activities [3]; however, few such scientific reports are available [4–9]. Some scientific reports that revealed an effect of activity restrictions on physical

activity were based on questionnaires such as the International Physical Activity Questionnaire [8,9], which are subjective methods. Moreover, those studies were conducted after the pandemic started and were examined by reminding participants of pre-pandemic life activities. Therefore, their results may have been greatly affected by participants' recollection of lockdown and self-restraint. Some studies have reported a decrease in the number of steps taken as an objective measure of behavioral restriction [3–5], suggesting that people's walking behavior was affected. However, to our knowledge, no studies have evaluated the effect of restriction on walking parameters, such as walking speed, step length, and cadence. Walking speed and step length are important indicators associated with health outcomes in older individuals [10–13], and it is meaningful to quantify the effect of activity restriction on walking parameters.

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We have developed a background smartphone application that measures steps taken, walking speed, step length, and cadence in daily life [14,15]. The application uses the step count application programming interface and the Global Positioning System (GPS) of the smartphone and has been used throughout Japan as a service to customers of private insurance companies since 2016. Using such data, self-restraint effects on daily walking parameters during the pandemic can be determined objectively.

In Japan, because of the rapid spread of COVID-19, a state of emergency was issued from April 7, 2020, in major cities and from April 16 to May 14, 2020, in other areas [16]. In a state of emergency, the Japanese government recommended that people avoid the “three Cs”—closed spaces, crowded places, and close-contact settings—for protection against infection. Although the government did not force citizens to stay home, restrict economic activities, such as work or meetings with friends, or dining in closed restaurants, people with comorbidities and older adults were advised to avoid crowded places and going out as much as possible. Some prefectures issued their state of emergency before the government’s state of emergency. Cities did not implement lockdown in Japan. However, people were requested to refrain from going out unnecessarily and urgently from the end of March in some prefectures, including the metropolitan area. In April, with the state of emergency, requests for restrictions on going out had spread nationwide [16]. Companies recommended telecommuting, and the government advised citizens to refrain from going out or eating and drinking in groups. A survey by mobile phone location-based services, wherein the population of each area can be estimated from the number of mobile phones located in each base station, reported approximately 50 % or more population reduction in urban areas and major stations [17]. This survey also showed that even after the state of emergency was lifted, the reduction in population in urban areas continued. Individuals limited their movement between cities and did not immediately return to pre-pandemic activities. The decrease in going out resulted in a decrease in outdoor walking, which may have affected walking parameters. This study aimed to determine the effects of such self-restraint recommended by the national and local governments on daily walking parameters.

2. Methods

2.1. Participants

The study participants were subscribers to a life insurance plan. At the time of first purchasing or during a regular review of their life insurance, 166,579 subscribers of private insurance service in Japan were requested to use a smartphone application that provided measurements of daily walking parameters (Fig. 1). Of those subscribers, 15,269 agreed to participate in the program and provided informed consent. Informed consent was collected when the participants first used the smartphone application, and all participants provided consent for the use of their measurements of walking parameters for scientific research.

The authors received anonymous data from the insurance company for all users of the daily-life step-monitoring application from October 1, 2016, to June 15, 2020. Data from 2 March to 15 June in 2019 and 2020 were used for this study. In this study, we also obtained data for the years before 2018; however, the algorithm of the application changed after April 1, 2018, rendering it impossible to compare with the data before then; the analysis period was determined for 2 years. In total, we analyzed data from 3901 participants for whom walking parameters were available for each week in both years.

This research was reviewed and approved by the Tokyo Metropolitan Institute of Gerontology’s ethics committee (approval number No. K128, 2018), and conformed to the principles embodied in the Declaration of Helsinki.

2.2. Measurement of walking parameters

The application automatically and surreptitiously measured participants’ step counts per day, walking speed, step length, and cadence. The walking start time was determined by the response of the pedometer application programming interface (API) in the smartphone’s operating system. When a continuous, straight walking trajectory was detected by the pedometer API and GPS for a distance of at least 20 m, the walking speed was measured until interrupted. Once the application started, the participant’s walking speed was measured in the background while the participant walked outdoors (as GPS is limited to outdoor use). Excellent test-retest reliability of walking speed per week was reported using this application, where intraclass correlation coefficient, standard error of measurement (SEM), and minimal detectable change in 95 % confidence

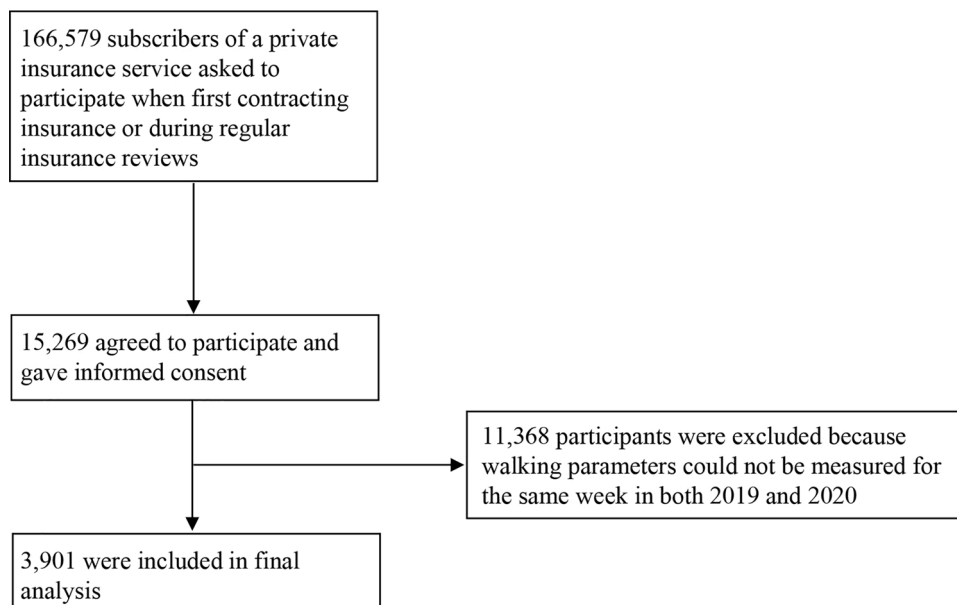


Fig. 1. A flow chart of participants in this study.

interval (MDC95) were 0.902, 0.036 m/s, and 0.101 m/s, respectively [14].

The application works on both iOS and Android and is available for download from both the Apple Store and Google Play. The developer of the application stated that its accuracy was confirmed with currently available smartphones (Sep 2016), but the data were not disclosed to the public. The validity and the test-retest reliability of measurement of walking parameters using this application were reported in our previous study [12].

2.3. Statistical analyses

All the measurements of walking parameters were aggregated by participants' identification number and measurement week, and average number of steps taken, walking speed, step length, and cadence for each week were calculated. Repeated-measures two-way analysis of variance was used to compare the number of steps taken, walking speed, step length, and cadence for each week between 2019 and 2020. Cohen's *d* effect size of the 2-year change in walking parameters during the period in which the state of emergency was issued (13–19 weeks from January 1) was calculated. Stratified analyses by gender were also performed. SPSS ver. 24.0 J (IBM Japan, Ltd., Tokyo, Japan) was used as the statistical software.

3. Results

Of 3901 participants, 932 were men and 2969 were women. Their mean (standard deviation) age was 60.3 (28.9) years (Table 1). They resided in all prefectures of Japan (Supplementary Table 1).

The number of steps at 9 weeks or later decreased by approximately 1000 in 2020 (approximately 3400 steps) compared to that in 2019 (approximately 4400 steps); this decrease was statistically significant ($p < .001$) (Fig. 2A). Conversely, the walking speed increased in 2020 (approximately 1.25 m/s) compared to that in 2019 (approximately 1.23 m/s); this difference was significant ($p < .001$) throughout the period when a state of emergency was issued (Fig. 2B).

Steps were also longer in 2020 (approximately 65.5 cm) than in 2019 (approximately 64.8 cm), with significant differences during the period of the state of emergency ($p < .001$; Fig. 2C). In terms of cadence, although there were significant differences for several weeks between the two years ($p < .001$), the differences were small (Fig. 2D). Details of these walking parameters are provided in Supplementary Table 2.

The effect size of the 2-year change in walking parameters during the period in which the state of emergency was issued was 0.30 for the number of steps, 0.17 for the walking speed, 0.11 for the step length, and 0.08 for the cadence.

As for the results of stratified analyses by gender, changes in walking parameters were smaller in men than in women (Supplementary Figs. 1, 2, Supplementary Tables 3, 4). The effect size of changes in walking parameters during the state of emergency in women was 0.37 for the number of steps, 0.16 for walking speed, 0.13 for step length, and 0.08 for cadence, while 0.19, 0.10, 0.07, and 0.07 in men, respectively.

Table 1
Demographic characteristics of the participants.

Age group (years)	Men (n = 932)		Women (n = 2969)		Overall (n = 3901)	
	n	%	n	%	n	%
Under 20	3	0.3	4	0.1	7	0.2
20–29	28	3.0	57	1.9	85	2.2
30–39	77	8.3	147	5.0	224	5.7
40–49	97	10.4	354	11.9	451	11.6
50–59	215	23.1	728	24.5	943	24.2
60–69	274	29.4	1059	35.7	1333	34.2
70–79	198	21.2	553	18.6	751	19.3
Over 80	39	4.2	65	2.2	104	2.7
Unknown	1	0.1	2	0.1	3	0.1

4. Discussion

Few studies have objectively evaluated the effects of COVID-19 behavioral restrictions on physical function, and none, to our knowledge, has specifically mentioned the effects on outdoor walking speed. Walking speed is well known as an accurate health-related predictor of dependency, cognitive decline, and death [10–13]. In the previous pooled analysis of large-scale cohort studies, the hazard ratio for survival per each 0.1 m/s faster-walking speed was 0.88 [10], that for bathing or dressing dependence was 0.68–0.74, and that for mobility difficulty was 0.73–0.74 [11]. Walking speed has been reported to be a predictor of future functional dependence [12], and step length is an independent factor of future cognitive decline [13]. If restrictions of going out due to the COVID-19 pandemic have caused changes in walking speed and step length, these health outcomes may also be affected in the long term. Therefore, walking speed may be important for estimating the long-term effects of the COVID-19 pandemic on human health.

Our results revealed a marked decrease in the average number of steps taken per week in outdoor walking during the state of emergency, indicating that the self-restraint measures greatly affected individuals' activity levels. This decrease was approximately 23 %, comparable to that reported in a previous study [4,5]. Outdoor walking speed, however, did not decrease during the state of emergency; in fact, it increased. Similarly, this tendency was observed in the result of a stratified analysis by the major cities, where a state of emergency was declared in advance, and other prefectures (data not shown). Although the walking parameters for the 17th week in 2019 showed extremely low values compared to those for the other weeks, that week is the "Golden week," which is a consecutive holiday week in Japan.

As the observed change in outdoor walking speed was 0.02 m/s, which was smaller than SEM and MDC95 in average walking speed per week reported in our previous study, the change was not clinically significant. The changes in walking speed and step length were smaller than those in the number of steps in terms of the effect size. However, as increased walking speed and step length were consistently noted during the state of emergency compared to those in the previous year, we interpreted that behavioral changes in walking were caused if people attempted to increase their walking speed by extending their step length. Previous studies reported that the number of steps per day had a positive correlation with the walking speed [18,19], whereas in this study, the walking speed slightly increased in contrast with the decrease in the number of steps. This also suggested behavioral change in walking, which may have protected further deterioration of health due to restricted activity. Decreased physical activity and mental health in the COVID-19 pandemic have been reported [8,20]. It has also been reported that the higher the physical activity level during the COVID-19 pandemic, the better the mental health [21,22]. As the opportunity of outdoor walking decreased, behavioral changes in walking may have occurred, such as walking exercise and increasing walking speed in daily life in order to maintain physical activity and mental health. We believe that individuals may have compensated for the decrease in the quantity of activity by increasing the intensity of activity.

As a result of stratified analysis by gender, changes in walking parameters were not remarkable in men compared to those in women. A previous study that investigated the reduction in steps of men and women during a state of emergency in Japan also reported that men had a lower rate of decrease in the number of steps than women and that older individuals had a lower rate of decrease in steps than younger individuals [5]. As male participants in this study included a slightly younger population than female participants, the change in the number of steps of men may have been smaller than that of women. As the decrease in the number of steps was small, the change in walking behavior could also be small.

Walking speed is the product of step length and cadence. In this study, the increase in walking speed was caused mainly by the extension

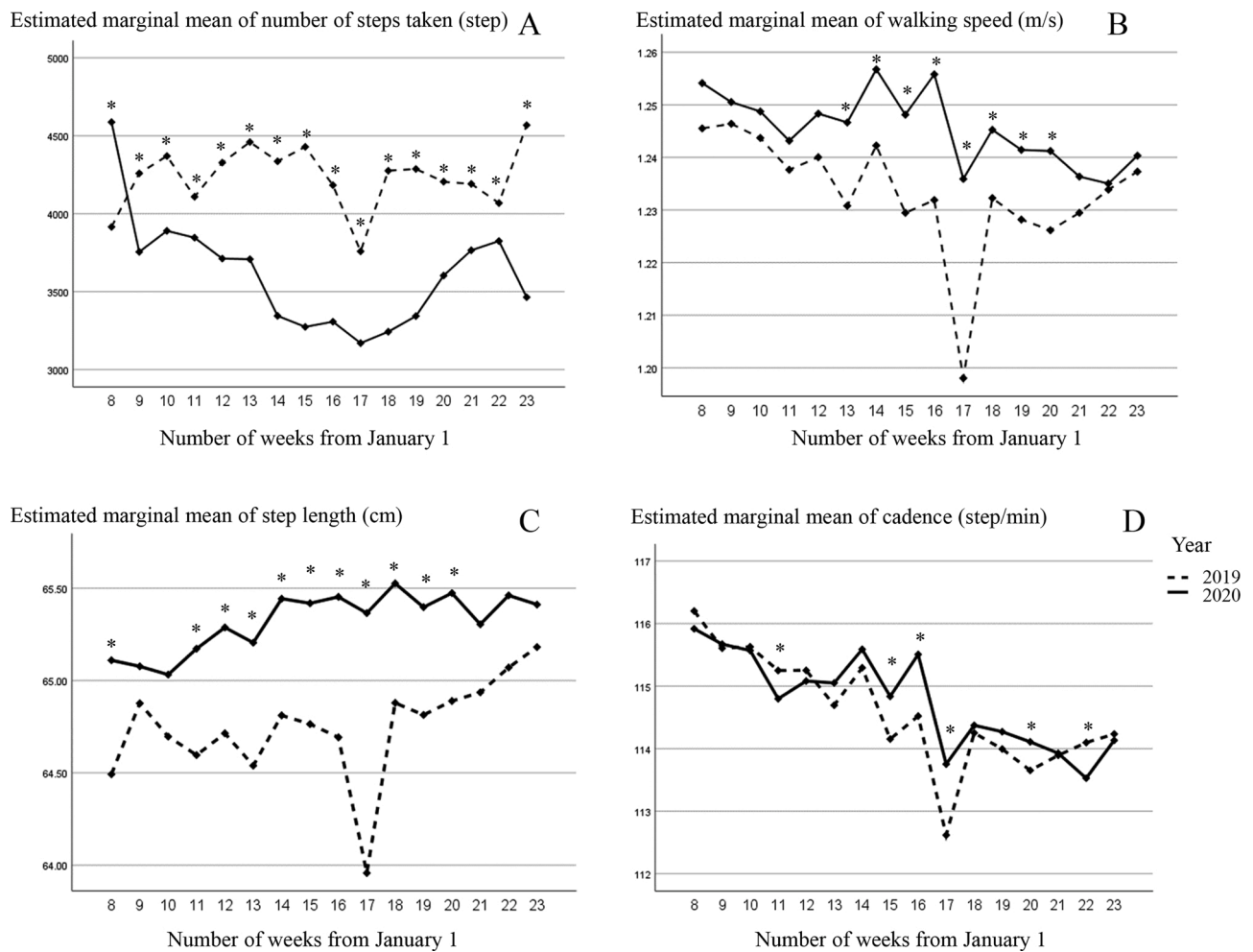


Fig. 2. Change in the number of steps taken (A), walking speed (B), step length (C), and cadence (D) per week in 2019 and 2020 (a state of emergency was issued from weeks 13 to 19 in 2020; the 17th week is the “Golden week,” which is a consecutive holiday week in Japan). * $p < .001$.

of step length. There is an optimal walk ratio at which energy consumption is most efficient [23]. This walk ratio can be maintained robustly regardless of speed. The change in step length observed in this study was larger than that in cadence; however, the change in step length was little, and the cadence also became slightly high, so the walk ratio was maintained around the optimum level of 0.006. Although not deviating from the optimal walk ratio, the participants walked faster with a strategy where step length was extended, which may be due to an attempt to increase energy expenditure. Although it is unclear why individuals chose to lengthen their steps, thereby deviating from the optimal walk ratio, we hypothesize that this was done to increase energy consumption.

4.1. Study limitations

This research was based on data obtained from a background smartphone application over a long period; this implies that the data may be biased toward health-conscious individuals, although the amount by which steps were reduced is similar to worldwide reported data [4] and other previous studies in Japan [5]. We used an application by smartphone GPS, so that measurement was limited to outdoor walking. Although outdoor walking decreased due to the request to refrain from going out, it is possible that indoor walking compensated for the number of steps lost in outdoor walking. A previous study reported that those who engaged in vigorous physical activity during the confinement period due to the outbreak of the COVID-19 had higher resilience [24]. In addition, as these measurements require GPS,

housebound persons were not included. Studies using other methods will be required to determine the impact of the pandemic on housebound persons. Step length can be normalized by body height [25], and there may be other factors to consider that affect walking parameters in this study, such as medical and social conditions. However, our data were obtained from secondary use of the application data provided by a life insurance company; thus, we could not acquire such additional information.

5. Conclusion

In this study, it was confirmed that the amount of activity per individual per week decreased in terms of the number of steps taken, as in previous reports. In contrast, it is interesting to observe that individuals' walking pattern changed, as if to compensate for their inactivity. Although changes in walking speed and step length were small compared to those in the number of steps, those changes were consistently seen during the state of emergency, suggesting that people attempted to change their walking patterns. Such behavioral changes may have protected further deterioration of health due to restricted activity.

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Declaration of Competing Interest

Kenji Murakawa is an employee of Taiyo Life Insurance Company, which developed the smartphone application used in this study and uses it to provide services; however, no funds were obtained from the company for this study. The other authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.gaitpost.2021.05.005>.

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