



Short Communication

Associations between seasonal meteorological conditions and the daily step count of adults in Yokohama, Japan: Results of year-round pedometer measurements in a large population

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ABSTRACT

People's year-round interpersonal step count variations according to meteorological conditions are not fully understood, because complete year-round data from a sufficient sample of the general population are difficult to acquire. This study examined the associations between meteorological conditions and objectively measured step counts using year-round data collected from a large cohort ($N = 24,625$) in Yokohama, Japan from April 2015 to March 2016.

Two-piece linear regression analysis was used to examine the associations between the monthly median daily step count and three meteorological indices (mean values of temperature, temperature-humidity index (THI), and net effective temperature (NET)).

The number of steps per day peaked at temperatures between 19.4 and 20.7 °C. At lower temperatures, the increase in steps per day was between 46.4 and 52.5 steps per 1 °C increase. At temperatures higher than those at which step counts peaked, the decrease in steps per day was between 98.0 and 187.9 per 1 °C increase. Furthermore, these effects were more obvious in elderly than non-elderly persons in both sexes. A similar tendency was seen when using THI and NET instead of temperature. Among the three meteorological indices, the highest R^2 value with step counts was observed with THI in all four groups.

Both high and low meteorological indices discourage people from walking and higher values of the indices adversely affect step count more than lower values, particularly among the elderly. Among the three indices assessed, THI best explains the seasonal fluctuations in step counts.

1. Introduction

The importance of an active lifestyle in preventing non-communicable diseases (NCD), physical dysfunction, and psychological disorders has been widely recognized, although most adults do not meet the recommended physical activity (PA) target (Lee et al., 2012). One of the voluntary global NCD targets for 2025 is a 10% reduction in the prevalence of insufficient PA (World Health Organization, 2013). Development of effective strategies to achieve this target requires understanding of the associations between meteorological conditions and PA.

Seasons (Levin et al., 1999; Newman et al., 2009; Tudor-Locke et al., 2004) and meteorological conditions (Chan et al., 2006; Matthews et al., 2001; Togo et al., 2005; Tucker and Gilliland, 2007), such as temperature, humidity, and wind speed, influence people's PA levels, particularly outdoor walking, the most common moderate intensity PA undertaken by people globally. Daily step count, as objectively

measured using a pedometer or accelerometer, explains most of the variation in PA (Tudor-Locke et al., 2011), eliminating the self-serving bias of self-reported measurements (Colpani et al., 2014; Sabia et al., 2014; Senso et al., 2014).

However, people's year-round intrapersonal step count variations and variations according to meteorological conditions are not fully understood, because complete year-round data from a sufficient sample of the general population are difficult to acquire.

We examined the associations between meteorological conditions and objectively measured step counts using year-round data from a large cohort of the “Yokohama Walking Point” program (YWPP) of Yokohama City in Japan.

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2. Methods

2.1. Yokohama walking point program

Yokohama City (population, approximately 3.7 million) launched the YWPP in November 2014 to encourage citizens to improve their health and enjoy a healthier life expectancy as the population ages and disease structure changes in Japan.

A free pedometer (Omron HJ-326F, Japan) was given to citizens aged ≥ 40 years who volunteered to participate. Participants were awarded points by scanning their pedometers over special readers installed at approximately 1000 stores and other types of facilities in the city. Accumulation of a certain number of points made participants eligible to win prizes. The scanned data were sent to a data server through the Internet, and participants could monitor step counts and ranking among all participants using a PC or a smartphone.

Providing pedometers seems to be a popular intervention for promoting walking (Ogilvie et al., 2007), and several municipalities in Japan provide pedometers. We used the data from the YWPP because it has, by far, the largest number of participants.

2.2. Pedometer data

Pedometer data, which the city collected from 161,681 YWPP participants who registered before March 31, 2016, were provided and used for this study. The number of participants was equivalent to 7.5% of the city's population aged ≥ 40 years (4.5% of the city's population between 40 and 64 years, 12.1% of the population ≥ 65 years). Data on sex and date of birth were obtained from registered information, and age as of April 1, 2015 was calculated.

Participants with pedometer data for ≥ 20 days/month in all twelve months from April 2015 to March 2016 were included in the analyses ($N = 24,625$). The cut-off threshold was selected balancing the number of samples with the validity of the analysis after examining other cut-off values. The daily mean step count for each month was calculated for each participant using the hourly step count.

2.3. Meteorological data

Yokohama City has a humid subtropical climate, in which most of the country is located, with a monthly mean temperature range of 6.2 °C to 26.8 °C and relative humidity range of 56.5% to 80.6%. To assess meteorological conditions from April 1, 2015 to March 31, 2016, the daily mean temperature, daily mean relative humidity, and daily mean wind speed at the Yokohama Local Meteorological Office, located at the eastern side of the city (35°26'4"N, 139°39'2"E), were obtained from the website of the Japan Meteorological Agency (<http://www.jma.go.jp/jma/>; accessed Nov 9, 2016). This office is the only weather observation point in the city, one of 1300 points in Japan.

2.4. Analyses

To investigate the monthly year-round fluctuation in step count, median steps per day for each month by sex and five-year age groups were calculated. As meteorological indices, the averages of daily mean temperature, temperature-humidity index (THI), and net effective temperature (NET) (World Meteorological Organization and World Health Organization, 2015) for each month were calculated using the following formulae:

$$\text{THI} = 0.81 T + 0.01 (\text{RH}) (0.99 T - 14.3) + 46.3;$$

$$\text{NET} = 37 - (37 - T) / (0.68 - 0.0014 (\text{RH}) + 1 / (1.76 + 1.4v^{0.75})) - 0.29$$

$$T(1 - 0.01 (\text{RH}))$$

where:

T: air temperature (°C).

RH: relative humidity (%).

v: wind speed (m/s).

In this analysis, T, RH, and v are the average daily mean values in each month.

To evaluate the associations between the monthly median daily step count and the three meteorological indices, participants were divided into four groups by sex and age (< 65 and ≥ 65 years), and scatter diagrams of the monthly median daily step count versus each meteorological index were drawn separately for the four groups. The age of 65 years is the threshold for elderly persons in Japan, and the employment rate decreases most at this age. Two-piece linear regression analysis was used to examine the associations, because it is expected that both high and low meteorological conditions discourage people from walking. The Solver add-in of Microsoft Excel was used for the analysis.

3. Results

Compared to the Yokohama population aged ≥ 40 years, the proportion of males was slightly lower (48.7% vs. 46.3%), and the mean age was older (60.3 ± 13.9 vs. 66.1 ± 10.5 years) for the participants analyzed.

The median step counts for each month were calculated by sex and age groups (Supplemental Table 1). The median step counts for males peaked in the 60–64 year group and were comparatively lower among those in their 40s. In females, peak step counts were seen in the 45–49 year group, with a monotonic decrease after the 60s. The age-related decrease in step count occurred earlier in females. The decrease with age was particularly marked after the 80s in both sexes. These tendencies were almost the same in all months. Regarding fluctuations in monthly median steps per day, step counts were high in October and May and low in August and January for all four groups.

Figs. 1, 2, and Supplemental Fig. 1 show the associations between the monthly median daily step count and the monthly mean daily temperature, THI, and NET in each of the four groups. According to the two-piece linear regression analysis, the number of steps per day peaked at temperatures between 19.4 and 20.7 °C (THI 66.2–67.4; NET 13.3–14.3). At lower temperatures, the increase in steps per day was between 46.4 and 52.5 steps per 1 °C increase (36.0–39.2 steps per 1 THI increase; 43.8–46.4 steps per 1 NET increase). At temperatures higher than those at which step counts peaked, the decrease in steps per day was between 98.0 and 187.9 per 1 °C increase (69.6–124.4 steps per 1 THI increase; 89.3–158.8 steps per 1 NET increase), showing that higher values of the meteorological indices adversely affect step count more than lower values. Furthermore, these effects were more obvious in elderly than non-elderly persons in both sexes. Among the three meteorological indices, the highest R^2 value with step counts was observed with THI, followed by NET and temperature in all four groups.

4. Discussion

Our study results highlight the fact that fluctuations in step counts are largely associated with meteorological conditions. Monthly differences in the four groups were comparable to those between age groups, although less than those between the sexes. Although the use of a pedometer might have motivated participants to increase their step counts (Bravata et al., 2007; Ogilvie et al., 2007), their seasonal fluctuation due to meteorological conditions is expected to be similar to that in the overall population.

The temperature at which step counts peaked was between 19.4 and 20.7 °C, which was higher than the result of quadratic regression (17 °C) in the study by Togo and colleagues (Togo et al., 2005). At lower temperatures, the increase in step counts was between 46.4 and 52.5 per 1 °C increase, which was more than that seen in Chan and colleagues' study (2.9% step increase per 10 °C) (Chan et al., 2006), which adjusted for snowfall and snow on the ground. At temperatures

higher than the peak step count temperature, the decrease in step counts per 1 °C increase was more than double the increase with lower temperatures.

Among the three indices assessed, regression analysis showed that THI best explains the seasonal fluctuations in step counts, indicating that not only temperature, but also relative humidity, affects people's activity level, particularly among the elderly. The associations between meteorological conditions and step counts relative to age should be considered when giving advice to encourage PA. For instance, designating safe routes for the elderly to walk before the dawn would be useful in hot and humid months, since their step counts are strongly associated with these meteorological conditions. Moreover, air-conditioned spaces, such as indoor shopping malls (Belza et al., 2015), could be introduced to encourage PA in both hot and cold months.

Our findings suggest that PA targets that include outdoor walking should consider regional year-round climate. For example, many countries have set their recommended daily PA targets in harmony with the WHO target (World Health Organization, 2013). The daily step count target in the Japanese national health promotion plan was set to increase by 1500 steps/day by sex and age (< 65 and ≥ 65 years), based on a one-day survey in November 2010 (Minister of Health Labour and Welfare of Japan, 2012). The median steps per day in November are comparatively similar to the annual mean, although it is 1.4–2.0% higher in women aged 55–74 years.

The limitations of the present study include a lack of background information about the participants, such as their health status and lifestyle. Such information has to be collected through a questionnaire survey, but there are no such data with large samples at present. Additionally, the data for precipitation and for holidays were not included, although there was no regular association between the regression residual and the number of days with precipitation or the holidays in each month.

The current study was conducted in a city with a humid subtropical climate. Using the results of the current study, step count data collected in different seasons and areas with similar climate can be compared, adjusting the meteorological effects. Further studies under different meteorological conditions are required to understand the associations between meteorological conditions and people's PA worldwide, and to create effective strategies for promoting PA year round.

Supplementary data to this article can be found online at <http://dx.doi.org/10.1016/j.pmedr.2017.07.009>.

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Conflict of interests

There are no conflicts of interest.

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All authors contributed to the study design and data interpretation. KH and JSL searched the literature. KH and YA contributed to data collection, data analysis, and figure design. KH wrote the first draft, and all authors critically reviewed the report.

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