Quantity and Quality of Physical Activity Are Influenced by Outdoor Temperature in People with Knee Osteoarthritis

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ABSTRACT

Purpose: Environmental factors are known to influence physical activity (PA) levels of healthy people, but little work has explored these factors in people with osteoarthritis (OA). The purpose of this study was to explore the influence of outdoor temperature on PA in people with knee OA. **Methods:** A total of 38 people with knee OA (10 women; mean age 54 y) wore an accelerometer around their waist for 7 consecutive days. Dependent variables from the accelerometers were three PA measures: (1) activity counts/day and time spent at or above moderate levels of PA with (2) a cut-point of 1,041 activity counts/minute (MVPA₁₀₄₁) and (3) a cut-point of 1,952 activity counts/minute (MVPA₁₉₅₂). Independent variables were age, sex, body mass index (BMI), and maximum daily outdoor temperature. Three linear regression analyses were conducted using the three PA dependent variables and independent variables. **Results:** After controlling for age, sex, and BMI, maximum daily outdoor temperature explained 9% of the variance in activity counts/day ($p = 0.042$), 10% of variance in MVPA₁₀₄₁ ($p = 0.032$), and 14% of variance in MVPA₁₉₅₂ ($p = 0.016$). Participants who engaged in more PA were younger and were exposed to warmer temperatures. **Conclusions:** Outdoor temperature and age influence the PA levels of people with knee OA. These factors should be considered when designing PA programmes.

Key Words: knee osteoarthritis; motor activity; temperature; weather.

RÉSUMÉ

Objectif : Les facteurs environnementaux sont reconnus pour influencer les niveaux d'activité physique (AP) des personnes en bonne santé, mais peu de travaux se sont penchés sur l'influence de ces facteurs chez les personnes souffrant d'arthrose. L'objectif de cette étude était donc d'explorer l'influence de la température extérieure sur l'AP des personnes souffrant d'arthrose du genou. **Méthodologie :** Trente-huit participants souffrant d'arthrose du genou (10 femmes; moyenne d'âge de 54 ans) ont porté un accéléromètre autour de la taille pendant sept jours consécutifs. Trois mesures du niveau d'AP faisaient partie des variables dépendantes des accéléromètres : 1) somme d'activité/jour et temps passé en AP de niveau modéré ou supérieur, 2) un point de découpage de 1 041 décomptes d'activité/minute (APMV₁₀₄₁) et 3) un point de découpage de 1 952 décomptes d'activité/minute (APMV₁₉₅₂). Les variables indépendantes incluses étaient l'âge, le sexe, l'indice de masse corporelle (IMC) et la température extérieure maximale quotidienne. Trois analyses de régression linéaire ont été réalisées à l'aide des trois variables dépendantes d'AP et des variables indépendantes. **Résultats :** Après un contrôle de l'âge, du sexe et de l'IMC, la température extérieure maximale était à l'origine de 9% de la variation des décomptes d'activité/jour ($p = 0,042$), de 10% de la variation de l'APMV₁₀₄₁ ($p = 0,032$) et de 14% de la variation de l'APMV₁₉₅₂ ($p = 0,016$). Les participants qui faisaient davantage d'AP étaient plus jeunes et exposés à des températures plus chaudes. **Conclusions :** La température extérieure et l'âge influencent les niveaux d'AP des personnes qui souffrent d'arthrose du genou. Ces facteurs devraient être pris en compte lors de la conception de programmes d'AP.

Knee osteoarthritis (OA) has numerous physical consequences, including a decrease in physical activity (PA).¹ In a study by Farr and colleagues, only one-third of individuals with knee OA met the minimum recom-

mendation of 30 minutes of moderate-intensity PA 5 days a week.² Furthermore, the frequency and intensity of PA in women with hip or knee OA have been shown to be lower than in healthy controls.¹ These findings are

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extremely important, given the health benefits of PA and the inverse relationship between disease outcomes and regular PA.³

Although studies have investigated the quantity (frequency, accumulation) or quality (intensity) of PA in people with knee OA,^{2,4} more work is needed to explore the determinants of this reduced PA.^{1,5,6} Older age, increased body mass index (BMI), and severe knee pain have been associated with decreased PA in this population.^{7,8} Feinglass and colleagues' study of 241 participants with either knee OA or rheumatoid arthritis examined the influence of demographic variables (e.g., age, sex) and environmental conditions on PA measured with accelerometers;⁵ participants were randomized to a PA counselling programme or control treatment and were tested up to six times over 3 years. Decreased levels of PA were associated with older age, female gender, light or heavy rain, and cold ($<-7^{\circ}\text{C}$) or hot ($>24^{\circ}\text{C}$) temperatures. This study provides insight into the influence of environmental conditions on PA in people with knee OA. However, caution should be used when interpreting Feinglass and colleagues' results because participants were receiving interventions aimed at increasing PA, and the PA of people with knee OA or rheumatoid arthritis may be influenced differently by factors such as environmental conditions.

Environmental factors also influence PA in healthy adults, particularly in climates with extreme temperatures. Increased outdoor temperature has been found to be associated with increased step counts and accelerometer-derived variables of PA.^{9,10} However, a decrease in PA was reported in accelerometer-measured PA variables in community-dwelling adults when temperatures rose above 30°C .¹¹ Thus, it is clear that environmental conditions influence PA levels in healthy older adults; however, the strength of the relationship between environmental conditions and PA is not clear in patient populations that report a relationship between their disease symptoms and weather, including people with knee OA.¹²

The purpose of our study was to explore the influence of outdoor temperature on objectively measured PA, quantified with accelerometer-derived variables that measure quantity and quality of PA, in people with knee OA. This relationship was explored after controlling for other variables shown to relate to PA in people with knee OA, including age, sex, and BMI.^{5,7,8}

METHODS

Study design and participants

Using a cross-sectional design, we collected data in southwestern Ontario, Canada, from October 2008 to February 2010. Participants were recruited via convenience sampling from a tertiary health care centre and were participating in a study examining knee loading and pain in people with knee OA.¹³ Participants were included

if they were diagnosed with knee OA according to the criteria proposed by the American College of Rheumatology,¹⁴ were between 40 and 80 years of age, reported knee pain within the last week, and presented with at least mild radiographic knee OA on anterior-posterior standing radiographs (i.e., a Kellgren-Lawrence score of at least 2/4).¹⁵ Exclusion criteria were lower-extremity surgery within the last 12 months, knee injections within the last 3 months, previous lower-extremity joint replacement, neurological or cardiovascular conditions that would greatly restrict mobility (e.g., angina pectoris, bronchitis, previous spinal cord injury), or an inability to understand English. The study was approved by the local research ethics board, and all participants provided written informed consent before study enrolment.

Procedures

Participants' PA levels were captured using accelerometers (model GT1M, ActiGraph, Pensacola, FL) that sample changes in vertical acceleration at 30 Hz. Prior studies have demonstrated the reliability and validity of data produced by accelerometers for measuring PA in adults.¹⁶⁻¹⁹ Accelerometers provide an objective measure of PA that is not subject to the recall biases of self-report measures; furthermore, previous research has found that data from accelerometers, specifically the variable activity counts, predict the metabolic requirements (MET) to maintain health and functional independence in adults.^{16,20} Based on this work, which compared accelerometer-derived activity counts to oxygen consumption measured with spirometry, "cut-points" predict the intensity of movement recorded by an accelerometer, allowing researchers to determine objectively whether daily PA levels meet current PA guidelines.²¹

The *epoch*, which represents the time period for which data are written to the accelerometer's memory, was set at 1 minute.¹⁸ Each participant was instructed to wear the accelerometer around the waist, at the mid-axillary line, over the leg under investigation. The accelerometers were secured using an elastic band, and participants were asked to wear them for 7 consecutive days. Accelerometers were worn during all waking hours and removed during sleep, bathing, and swimming. To ensure that PA throughout the day was captured, only days on which the accelerometer was worn for >12 hours were analyzed; data from participants who did not wear the device for 12 hours/day on at least 5 of the 7 days were excluded from the final analysis. We contacted participants twice during the week, via email or telephone, to encourage compliance.

Dependent variables

The accelerometers quantified PA in terms of activity counts. The first dependent variable was the average daily activity count (activity counts/day); higher values suggest greater quantity or frequency of daily PA. The second dependent variable was the average daily time

spent at or above moderate and vigorous PA (MVPA); higher values represent higher quality or intensity of daily PA. MVPA intensities were explored because the American College of Sports Medicine and the American Heart Association recommend at least 30 minutes of moderate PA 5 days/week.³ Since cut-points for MVPA have not yet been established in people with knee OA, previously published values were used to determine MVPA (1) with a cut-point of 1,041 and (2) with a cut-point of 1,952. For the first cut-point, accelerometer-registered activity counts/minute $\geq 1,041$ represented at least moderate PA (MVPA₁₀₄₁). This was based on healthy older adults with an average age of 70 years ambulating at 3.2 km/h.²⁰ The second cut-point was set at 1,952 activity counts/minute for at least moderate PA (MVPA₁₉₅₂).¹⁶ This cut-point was calculated in 25 men (mean age 25 y) and 25 women (mean age 23 y) ambulating on a treadmill over various speeds. The number of minutes spent in MVPA each day was determined and averaged over the week for both MVPA₁₀₄₁ and MVPA₁₉₅₂.

Independent variables

Age, sex, body mass index

Participants self-reported age, sex, and height on a demographic questionnaire. Body mass was determined using a force plate (Model OR6-5, Advanced Mechanical Technology Inc., Watertown, MA). BMI was calculated from height and mass measurements ($\text{BMI} = \text{mass}/\text{height}^2$).

Maximum outdoor temperature

Maximum daily outdoor temperature was studied as an environmental factor that could influence PA. We collected temperature information from the National Climate Archive published by Environment Canada.²² After identifying the weather station closest to each participant's city or town of residence, we recorded the local maximum daily outdoor temperature for each day the participant wore the accelerometer for at least 12 hours and averaged these daily temperatures together.

Data analysis

Our sample-size calculation was based on four independent variables explaining 30% of the variance in the dependent variable, with the last variable entered into the model explaining 10%; statistical significance was set at $p < 0.05$, and the calculation accounted for a 15% drop-out rate.²³ This calculation determined that a minimum of 38 participants would be needed; we rounded this number up to 40.

Descriptive statistics were calculated for the independent and dependent variables. Accelerometer compliance was examined by calculating the mean number of days and hours that participants wore the accelerometers. To investigate whether differences existed between participants who wore the device for only 5 or 6 days and those who wore it for all 7 days, we compared these

groups on the dependent and independent variables, using independent *t*-tests with statistical significance set at $p < 0.05$. Pearson correlation coefficients were used to examine bivariate relationships between the continuous study variables. Point biserial correlation coefficients calculated the correlation between the dichotomous variable (sex) and the continuous variables.

To answer the research question, we performed three separate sequential, hypothesis-driven forward linear regression analyses to explain the variance in each of the dependent variables (activity counts/day, MVPA₁₀₄₁, and MVPA₁₉₅₂). The independent variables were entered into the analyses in the following order: age, sex, BMI, and maximum daily outdoor temperature. The additional explained variance provided by maximum daily outdoor temperature was considered significant if $p < 0.05$. In addition, histograms of the residuals, plots of the residual against the predicted dependent variable values, and collinearity diagnostics, including variance inflation factors and tolerance, were examined to test the appropriateness of the final regression analyses. Analyses were completed using the Statistical Package for the Social Sciences version 17.0.2 (SPSS Inc., Chicago, IL).

RESULTS

We recruited a total of 40 participants. Data from two participants were not included in the final analysis: one participant did not complete data collection due to time constraints; another participant reported previously suffering a stroke after being enrolled in the study, and her data were therefore excluded. The group characteristics for the remaining 38 participants (10 women) are given in Table 1. For the 28 participants who were diagnosed with bilateral knee OA, the knee with the highest self-reported symptoms was selected as the study leg. Mild, moderate, and severe radiographic knee OA in the study leg was present in 18, 14, and 6 participants, respectively, according to Kellgren–Lawrence scores.

Table 1 also gives descriptive statistics for the dependent and independent variables. A total of 20 days were excluded from the analysis because the accelerometer was worn for < 12 hours on those days. No participant was excluded from the final analysis for non-compliance, as all participants had worn the device for > 12 hours/day on at least 5 days. On average, participants wore their accelerometers for 6.5 days, 14.8 hours/day. We found no statistical differences between those who wore the device for 5 or 6 days ($n = 15$, 5 women) and those who wore it for 7 days ($n = 23$, 5 women) for any of the variables (see Table 1). On average, participants accumulated 78 minutes/day of MVPA₁₀₄₁ and 21 minutes/day of MVPA₁₉₅₂. Pearson and point biserial correlation coefficients for the independent and dependent variables are shown in Table 2.

The regression analysis for activity counts/day (PA quantity) shows that age, sex, and BMI accounted for

Table 1 Group Characteristics and Study Variables

Variable	Entire sample (<i>n</i> = 38, 10 women)		5/6 d* (<i>n</i> = 15, 5 women)	7 d† (<i>n</i> = 23, 5 women)
	Mean (SD)	Range	Mean (SD)	Mean (SD)
Age, y	54 (7)	43–72	55 (7)	53 (7)
Height, m	1.75 (0.10)	1.50–1.88	1.74 (0.11)	1.76 (0.09)
Mass, kg	93.3 (16.6)	58.5–128.2	92.0 (19.8)	94.1 (14.7)
BMI, kg/m ²	30.4 (4.2)	20.8–41.2	30.4 (5.4)	30.3 (3.4)
Maximum outdoor temperature, °C	9.3 (10.8)	–6.5–27.6	7.5 (10.0)	10.5 (11.4)
Activity counts, no./d	260,197 (95,651)	100,619–469,554	250,806 (90,179)	266,322 (100,562)
MVPA ₁₀₄₁ , min/d	78 (37)	14–173	78 (39)	78 (36)
MVPA ₁₉₅₂ , min/d	21 (15)	2–73	18 (10)	23 (18)

*Participants who wore the accelerometer for only 5 or 6 days.

†Participants who wore the accelerometer for 7 days.

MVPA₁₀₄₁ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,041; MVPA₁₉₅₂ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,952.

Table 2 Correlation Coefficients between Study Variables*

Variable	Sex	BMI	Maximum temperature	Activity counts/day	MVPA ₁₀₄₁	MVPA ₁₉₅₂
Age	0.00	0.12	–0.18	–0.50‡	–0.47‡	–0.41‡
Sex	–	0.11	–0.03	0.05	0.10	0.11
BMI		–	–0.08	–0.02	–0.07	0.03
Maximum temperature			–	0.38†	0.40†	0.43‡
Activity counts/day				–	0.93‡	0.85‡
MVPA ₁₀₄₁					–	0.74‡
MVPA ₁₉₅₂						–

*Pearson correlation coefficients were used to compare continuous variables; point biserial correlation coefficients were used to compare the dichotomous variable (sex) and continuous variables.

†*p* < 0.05, two-tailed.

‡*p* < 0.01, two-tailed.

MVPA₁₀₄₁ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,041; MVPA₁₉₅₂ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,952.

25% of the explained variance in activity counts/day (see Table 3). Only age explained a significant (*p* = 0.002) portion of variance; younger age was associated with increased activity counts/day (see Table 2). In the final step of the analysis, maximum daily outdoor temperature captured a significant portion of variance (9%, *p* = 0.042); increased maximum daily outdoor temperatures were associated with increased activity counts/day, representing PA quantity (see Tables 2 and 3).

Examination of the regression analysis for MVPA₁₀₄₁ (PA quality) revealed that age, sex, and BMI accounted for 23% of the explained variance in MVPA₁₀₄₁ (see Table 3). Again, only age explained a significant (*p* < 0.003) portion of variance; younger age was associated with increased MVPA₁₀₄₁ (see Table 2). Maximum daily outdoor temperature was entered on the final step and accounted for a statistically significant (*p* = 0.032) amount of vari-

ance (10%); higher maximum daily outdoor temperature was associated with increased time spent in MVPA₁₀₄₁, representing quality of PA (see Tables 2 and 3).

Finally, the regression analysis for MVPA₁₉₅₂ showed that age, sex, and BMI accounted for 18% of the explained variance in MVPA₁₉₅₂ (see Table 3). Only age explained a significant (*p* = 0.011) portion of variance; younger age was associated with increased MVPA₁₉₅₂ (see Table 2). Maximum daily outdoor temperature accounted for an additional 14% (*p* = 0.016) of the variance in MVPA₁₉₅₂; higher maximum daily outdoor temperature was associated with increased quality of PA (MVPA₁₉₅₂) (see Table 2).

For the regression analyses, examination of the residuals demonstrated normal distribution, and evidence was consistent with linear relationships. The plots showed consistent variance in the residuals, which indicates that they did not depend on the values of the predicted dependent

Table 3 Summary of Linear Regression Analyses for Activity Counts/Day, MVPA₁₀₄₁, and MVPA₁₉₅₂

Dependent variable	Step	Independent variable	R^2	Adjusted R^2	R^2 change	F change	p^*
Activity counts/day	1	Age	0.25	0.23	0.25	11.72	0.002
	2	Sex	0.25	0.21	0.00	0.14	0.71
	3	BMI	0.25	0.18	0.00	0.06	0.81
	4	Maximum temperature	0.34	0.26	0.09	4.49	0.042
MVPA ₁₀₄₁	1	Age	0.22	0.20	0.22	10.33	0.003
	2	Sex	0.23	0.19	0.01	0.48	0.49
	3	BMI	0.23	0.17	0.00	0.03	0.86
	4	Maximum temperature	0.34	0.25	0.10	5.00	0.032
MVPA ₁₉₅₂	1	Age	0.17	0.14	0.17	7.18	0.011
	2	Sex	0.18	0.13	0.01	0.47	0.50
	3	BMI	0.18	0.11	0.00	0.17	0.68
	4	Maximum temperature	0.32	0.23	0.14	6.50	0.016

* p -values represent the p -value for the F change statistics.

MVPA₁₀₄₁ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,041; MVPA₁₉₅₂ = daily time spent in moderate and vigorous physical activity with a cut-point of 1,952.

variables. Diagnostic statistics also revealed no excessive collinearity between independent variables entered into the analyses, which indicates that the analyses were appropriate and did not violate assumptions associated with linear regression.

DISCUSSION

Both quantity and quality of PA in people with knee OA were associated with outdoor temperature. Specifically, warmer weather was associated with both increased PA levels (PA quantity) and increased time engaging in moderate and vigorous PA (PA quality). This positive relationship between higher outdoor temperatures and PA in our participants with knee OA is similar to those found in studies of healthy adults: population-based surveys and objective measures of PA among healthy adults have shown lower levels of PA in colder temperatures than in warmer temperatures.^{9,24–26} However, studies using accelerometers to capture PA have found a decline in PA with extreme heat,^{11,26} specifically, a decline in PA at temperatures $>30^{\circ}\text{C}$ among older adults in Canada and a decline in PA over a range from 17°C to 29°C among older adults in Japan.^{11,26} We collected data over two fall/winter seasons and one spring/summer season in a region of Ontario, Canada, where outdoor maximum temperature ranged from -6.5°C to 27.6°C ; temperatures were likely not high enough to demonstrate a decrease in PA during hot days. Nevertheless, both healthy adults and adults with knee OA appear to be more active when outdoor temperatures are moderate.⁵ These findings should be considered when designing PA programmes, since compliance may be lower during winter months or, based on findings from other studies,^{11,26} during periods of extreme heat. In climates where outdoor temperatures are moderate for only 4–6 months of the year,

clinicians should focus on alternative strategies to encourage PA during extremely cold or hot months, including promoting indoor PA programmes that demonstrate good participant compliance.

Our study examined only the influence of outdoor temperature on PA. However, other environmental factors have also been shown to influence PA. In one study, rain, snowfall, and wind speed demonstrated relationships with pedometer-measured step counts among adults receiving a behavioural intervention designed to improve PA.⁹ Similarly, rain and snowfall showed associations with accelerometer-derived PA variables in people with knee OA or rheumatoid arthritis enrolled in a study examining the effectiveness of a PA counselling programme.⁵ However, another study found no relationship between precipitation and wind speed and accelerometer-measured PA in older adults enrolled in a drug trial.¹⁰ Various personal factors, including age, sex, and health status, likely play a role in mediating the influence of environmental conditions on PA.⁹ Further research is needed to understand these complicated relationships.

It is not surprising that increased PA was associated with younger age among participants with knee OA. Studies using multiple measures of PA, including self-report questionnaires, pedometers, and accelerometers, have previously found lower levels of PA among older adults than among younger adults.^{7,27,28} It is important to encourage older adults with and without disease to remain physically active so that they can gain the health benefits associated with PA.

Different cut-points changed the quality of PA, assessed by magnitude of MVPA. Our study used cut-points of 1,041 and 1,952 activity counts per minute to represent PA greater than or equal to moderate intensity. The

threshold of 1,041 MVPA was determined in a study of healthy older adults (mean age 70 y);²⁰ the threshold of 1,952 MVPA was determined in a study of younger adults (mean age 23 y and 25 y for men and women respectively).¹⁶ In our study, varying the cut-point did not substantially influence the relationship between MVPA and maximum daily outdoor temperature; however, varying the cut-point will influence the total time spent in MVPA. A previous study examining MVPA among women with knee and hip OA used a cut-point of 2,224 activity counts/minute,² derived by averaging other previously published cut-points. In comparison, activity counts from accelerometers are usually compared to oxygen consumption to establish activity count cut-points that relate to PA intensity.^{16,20} The mean MVPA in this previously published study was 25 minutes/day,² much lower than the 78 minutes/day for MVPA₁₀₄₁ found in our study but similar to the 21 minutes/day for MVPA₁₉₅₂. This finding demonstrates the influence cut-points have on determining time spent in MVPA. Calculating the intensity of PA from oxygen consumption using a portable metabolic analyzer and comparing this to accelerometer measures would produce more accurate cut-points. More work is needed to determine specific cut-points appropriate for people with knee OA in different age groups.

Our study has several limitations. One is that participants self-selected for enrolment in the study, and therefore may have been more physically active than the general population of people with knee OA. In addition, a greater proportion of women would have been beneficial, but the sample recruited reflected the patients referred to the health care centre. Second, accelerometers worn at the waist assess PA of the lower extremity/trunk and thus underestimate the energy cost from upper-extremity activities.²⁹ Third, the mediating effect of symptoms on the relationship between PA and weather should be investigated, since patients with arthritis report that weather conditions influence their symptoms.¹²

CONCLUSIONS

Both quantity and quality of PA in people with knee OA are influenced by maximum outdoor temperature and age. These factors should be considered when designing an intervention aimed at increasing PA participation in this group. Interventions that account for temperature fluctuations over the course of the year, such as indoor PA programmes, should be used in areas where weather is extremely cold in winter or extremely hot in summer.

KEY MESSAGES

What is already known on this topic

People with knee osteoarthritis (OA) are less physically active than healthy people. However, determinants of this decreased physical activity, including various environmental conditions, have not been investigated in people with knee OA.

What this study adds

Outdoor temperature and age influence the physical activity levels of people with knee OA such that lower temperatures and increased age are associated with decreased physical activity. These factors should be considered when designing physical activity programmes.

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