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Moderating Effects of Weather-related Factors on a Physical Activity Intervention

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Abstract

Introduction—The purpose of this study is to identify whether weather-related factors moderate the effect of a physical activity (PA) intervention.

Methods—Participants (N=204, 77% female, mean age 33 [SD=11] years, mean BMI 28.2 [SD=7.1] kg/m²) from the Make Better Choices 1 trial enrolled April 2005 to April 2008, were randomized to one of two treatment conditions: (1) increase moderate to vigorous physical activity (MVPA) treatment group, or (2) decrease sedentary behavior control group. Participants wore an accelerometer for 5 weeks: a 2-week baseline assessment followed by a 3-week intervention. Accelerometer data were used to estimate minutes/day of MVPA. Average daily temperature, day length, and precipitation were obtained from the National Climatic Data Center and combined with the accelerometer data. Linear mixed effects models were used to determine whether these weather-related factors moderated the effect of the intervention on MVPA. Separate models were fit for season, daily average temperature, and day length.

Results—There was a significant moderating effect of season on MVPA such that the PA intervention, as compared with control, increased MVPA 10.4 minutes more in the summer than in the winter (95% CI=1.1, 19.6, $p=0.029$). There was a significant moderating effect of daily temperature such that every 10°F increase in temperature was associated with an additional 1.5 minutes/day increase in the difference in MVPA increase between the two intervention conditions (95% CI=0.1, 2.9, $p=0.015$). There was a significant moderating effect of day length such that every additional hour of daylight was associated with a 2.23-minute increase in the PA intervention's impact on increasing MVPA (95% CI=0.8, 3.7, $p=0.002$).

Conclusions—Day length and temperature had a significant moderating effect on change in MVPA during a PA intervention such that the intervention was less effective on colder days and on shorter days, independently. These results suggest that strategies to overcome environmental barriers should be considered when designing PA interventions for adults.

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INTRODUCTION

Although the benefits of living a physically active lifestyle have been well documented, more than half of U.S. adults remain inactive.¹ Often cited barriers to increasing physical activity (PA) include lack of opportunities to be active, safety concerns, and weather.² A review study by Chan and Ryan³ demonstrates a strong association between weather parameters and change in PA, in the absence of intervening factors. These results indicate that factors, such as temperature and precipitation, are significant determinants of usual PA participation. Although it is not possible to change weather, understanding the extent to which it can impede PA participation could inform the development of future activity programming.

This study is an exploratory analysis of the impact of weather factors on the effect of a PA intervention. Two groups previously have investigated seasonal influences on the magnitude of the effect of a PA intervention. Williams et al.⁴ examined the effect of season on walking time in adults in the United Kingdom during a 6-week walking intervention and at a 6-month follow-up. No seasonal effect on stepping time was observed in the study. Similarly, Chan and colleagues⁵ examined the effect of season within a 12-week PA intervention in Canada. The authors found a positive association between temperature and steps per day; steps increased 2.9% with every 10°C increase in temperature. Further, precipitation and wind had an inverse relationship with steps taken per day.

Both of these studies examined interventions that were directed at increasing walking behaviors (steps). No study to date has examined how seasonality may affect PA intensity variables throughout an intervention, as measured objectively by an accelerometer. It is unknown whether and how weather-related factors may alter the effects of an intervention on intensity-specific variables (i.e., moderate and vigorous physical activity [MVPA]).⁶ Therefore, the purpose of this study is to identify whether weather-related factors, such as season, weather conditions, and day length, moderate the effect of a PA intervention on MVPA in adults.

METHODS

Study Population

Participants were recruited between April 2005 and April 2008 for the Make Better Choices 1 Study (MBC1); a behavior change intervention focused on changing PA and eating behaviors. Inclusion criteria required adults to be aged 21–60 years, living in the Chicago area, and to self-report all of four risk behaviors: (1) low PA (<60 minutes MVPA), (2) high sedentary time (>90 minutes leisure screen time), (3) low fruit and vegetable intake (<5 servings per day), and (4) high saturated fat intake (>8% caloric intake). These behaviors were then confirmed via a 2-week observational run-in phase before participants were randomized to a treatment condition. Prior to enrollment all study candidates underwent an informed consent process approved by the Northwestern University and University of Illinois at Chicago IRBs.

Measures

MBC1 participants were randomly assigned to one of four intervention arms: (1) increase PA, decrease saturated fat consumption; (2) increase PA, increase fruit and vegetables; (3) decrease sedentary leisure screen time, decrease saturated fats; and (4) decrease sedentary leisure screen time, increase fruit and vegetable consumption. For the purpose of the current study the authors collapsed the four groups into two, based on the activity-related prescription: (1) an increase PA arm with a goal to increase MVPA to 60 minutes/day, or (2) a decrease sedentary behavior arm with a goal to decrease leisure time sedentary screen-time to less than 90 minutes/day. Detailed information about the intervention has been published elsewhere.⁷⁻⁹ Briefly, intervention components included an app on a mobile device that provided in-the-moment decisional support and feedback about diet and activity choices, remote coaching by telephone from a coach who received digital data about behavior from the participant's app, and financial incentives. The 3-week intervention phase used a step-up approach. The participant's week 1 behavior change goal was to attain half of their final target goal. The goal for weeks 2 and 3 was to attain the full, targeted goal and to maintain that level of performance until the end of the 3-week intervention. Participants wore an accelerometer-based activity monitor for 5 weeks total: during a 2-week baseline assessment phase and then again during the 3-week intervention phase. Results from this study intervention showed the increase PA group significantly increased their time spent in accelerometer-measured MVPA compared with the sedentary control group (added 9.7 [SD=1.5]) minutes, $p<0.001$).⁷

Participants wore an Actigraph 7164 activity monitor on the right hip for 5 weeks: 2-week baseline phase and 3-week intervention phase. Participants wore the activity monitor during all waking hours other than removing the device for any water-based activities, such as bathing or swimming. Activity data were collected in 60-second epochs and Freedson cutpoints were used to summarize the data as minutes of sedentary, light, and MVPA for each day the monitor was worn.¹⁰ Further information regarding activity monitor data reduction can be found elsewhere.⁷

Environmental data were downloaded from the National Climatic Data Center. Because all study participants were living in the Chicago area, all data were obtained from the Midway Airport, Chicago, IL measurement site. Environmental variables including average temperature per day (Fahrenheit), precipitation per day, and day length (hours) were merged with MBC1 activity monitor data by date. Precipitation was dichotomized into a yes/no variable because the range of precipitation on the continuous scale was small and zero-inflated. Season was categorized as spring, which included March, April, May; summer, which included June, July, August; fall, which included September, October, November; and winter, which included December, January, and February.

Statistical Analysis

All analyses were performed in STATA, version 13 in the fall of 2017. Descriptive statistics (e.g., mean, SD) were used to describe the study population. Linear mixed effects models were used to determine whether the environmental factors moderated the effect of the MBC1 intervention on MVPA. Moderation was assessed by estimating a three-way time $\times$ treatment

arm $\times$ environmental factor interaction. Four separate moderation models were fit for season (spring, summer, fall, winter), daily average temperature (continuous), precipitation (yes/no), and day length (continuous). Models investigating the moderating effect of temperature included main effects for day length and models investigating the moderation effects of day length included a main effect for temperature because of their similar temporal trends.

To illustrate the magnitude of the moderating effects of temperature and day length, for both temperature and day length, predicted difference in MVPA were calculated between treatment groups at four fixed levels of the moderator where the fixed levels corresponded to the average value of the moderator in each of the four seasons. For example, for the model investigating the moderating effects of temperature, predicted treatment effects when the temperature was 51°F (average spring temperature), 75°F (average summer temperature), 60°F (average fall temperature), and 27°F (average winter temperature) were calculated.

RESULTS

Participant characteristics for each intervention group are reported in Table 1. Overall, participants (N=204) were mostly female (77%), with an average age of 33 (SD=11) years, and average overweight BMI 28.2 (SD=7.1) kg/m². Table 2 provides a descriptive summary of the environment factors over the course of the study collection period and baseline PA across spring, summer, fall, and winter. As would be expected, there are differences in environment factors of interest across season, however, there were no differences in baseline PA across season.

Residual plots from the linear mixed effects models suggested the models fit the data well. These models investigating the moderating effects of season on the impact of the intervention showed a significant moderating effect of season on MVPA such that participants randomized to increase PA, as compared with those randomized to decrease sedentary behavior increased MVPA 10.4 minutes more in the summer than in the winter (95% CI=1.1, 19.6, $p=0.029$). There were no other significant contrasts between seasons.

The model investigating the moderating effect of precipitation found a significant main effect of precipitation on MVPA with a 1.9-minute (95% CI=0.6, 3.2, $p=0.004$) decrease in MVPA when precipitation is present. However, precipitation did not significantly moderate the effect of the PA intervention.

When specific natural environmental factors were examined, there was a significant moderating effect of daily temperature such that every 10°F increase in temperature resulted in a 1.5 minutes/day increase (95% CI=0.1, 2.9, $p=0.03$) in the difference in MVPA between treatment arms at follow-up with those in the increase PA group engaging in more MVPA than those in the reduced sedentary behavior group. Additionally, there was a significant moderating effect of day length such that every additional hour of daylight was associated with a 2.23-minutes greater difference in MVPA in the increase PA group compared with those in the reduced sedentary behavior control group (95% CI=0.8, 3.7, $p=0.002$) at follow-up. Full model output are presented in Appendix Tables 1–4.

Table 3 provides predicted values of MVPA by treatment condition at four different temperature values that were chosen because they were the average temperature in each season in Table 2. Results in Table 3 show there was a 6.5 minutes/day MVPA difference between the treatment groups during winter-like temperatures as compared with a 13.7 minutes/day MVPA difference between the treatment groups during warmer temperatures, with the increase PA group accumulating a greater amount of MVPA. These results suggest average temperature can significantly ($p=0.015$) moderate the impact of an intervention to increase PA with a greater PA intervention effect reported during warmer temperatures.

Similarly, Table 4 provides predicted values of MVPA by treatment condition at four different day length values that were chosen because they were the average day lengths in each season in Table 2. Results in Table 4 show a threefold greater MVPA difference between treatment groups when days are longest (15.7 minutes/day) compared with when days are shortest (4.9 minutes/day). Again, these results suggest day length significantly ($p=0.002$) moderates MVPA outcomes with the increase PA intervention producing a greater increase in MVPA when the days are longer.

DISCUSSION

Evidence indicates that a cross-sectional relationship exists between time spent in MVPA and season, temperature, and precipitation.³ However, to date, no study has examined—on accelerometer-measured MVPA—whether seasonal and weather-related factors moderate the impact of an intervention designed to increase MVPA.

Results revealed that season was a significant moderator of the intervention's effect on MVPA, showing a 10-minute greater impact on MVPA during the summer versus the winter. One previous study has examined the effect of season during a PA intervention.⁴ In a walking intervention, developed to increase steps per day over 6 months, investigators found no moderating effect of season on pedometer-measured step counts, with the intervention only producing a 200 steps/day increase, regardless of season. Although season did not have a significant effect on the intervention's ability to increase stepping, the authors found significant influence of season on control beliefs about the weather and intention to walk, suggesting a mechanism whereby weather or season could be a significant barrier to individuals increasing their steps per day. This provides interesting insight, relevant to the current results, into the process of eliciting a change in behavior. Both the Williams and French⁴ intervention and the current intervention targeted similar constructs, placing a focus on self-regulation; however, this study targeted an increase in MVPA instead of specifically walking behavior, with results showing a much larger intervention effect.⁹ These essential differences between intervention designs, guiding behavioral theories, and resultant outcomes may have played a large role in the difference in seasonal effect.

In addition to investigating the overall effect of season, the current study also focused on understanding what factors that characterize season could alter the outcome of a PA intervention. Therefore, the following factors were examined related to season: average temperature, precipitation, and day length. Results showed average temperature and day length both individually moderated the impact of the PA intervention on MVPA. One

previous study has examined the effect of temperature on PA following a PA intervention.⁵ In a walking intervention, authors found a significant main effect of temperature on pedometer-measured steps per day, showing an increase of 290 steps for every 10°C (18° change in Fahrenheit) increase in temperature. This equates out to about 2.9 minutes/day (based on a 20-minute mile), which is consistent with these findings of about 1.5 minutes per day difference with each 10°F increase in temperature. Although these values may seem trivial, when compared with the national per day average of MVPA in adults of <10 minutes, 1.5 minutes equates to a more than 10% increase. Furthermore, there was a significant moderation effect for day length. This study is the first to examine the moderating effect of day length on a PA intervention, although, previous cross-sectional research has shown an association between longer day and greater total accelerometer activity counts per day in older adults,¹¹ adults with arthritis,¹² and minutes per day of MVPA in children.¹³ Although average temperature and day length seem to go hand in hand in terms of the time of year in which they occur, the moderation effect of day length remained significant when average temperature was controlled for in the model investigating day length and vice versa. With these multiple factors independently affecting MVPA outcomes across an intervention, these results suggest that, beyond implementing a season-specific intervention, MVPA promotions should additionally account for the multiple environmental factors that generate seasonal effects.

Contrary to cross-sectional study findings that have shown a significant relationship between precipitation and time spent in MVPA, the current results indicated that precipitation was not a significant moderator of the effect of a PA intervention. By contrast, Chan and Ryan,⁵ found a significant effect of a rainy day (14 mm rain) on decreasing steps per day, post-walking intervention (−830 steps). Difference in results may be because of the lack of variability in the current study's precipitation data, which required dichotomization of the precipitation variable whereas Chan and Ryan examined the variable continuously. Additionally, factors such as type of precipitation (rain and snow) could have influenced active behaviors. However, the current results are promising suggesting that a day of rain or snow does not have a strong effect on accumulation of overall daily MVPA when engaging in a PA intervention.

Current findings have important practical implications for public health translation. A critical take away from the current results are that even when a comprehensive PA intervention is deployed, season and other weather-related factors can affect the ability of the intervention to produce change in PA behavior. Results indicate that season should be considered when designing interventions so as to allow further tailoring of the intervention dependent on temperature and day length in the period when the intervention will be rolled out. For example, incorporating environmental parameters as modifying mechanisms in a just-in-time adaptive intervention, an intervention framework identifying in real time when an individual needs assistance to complete a certain behavior (e.g., on a cold day) and immediately providing that support (e.g., suggesting the individual dress warm to be able to walk outside).¹⁴ From a large-scale public health PA promotion perspective, it could be advisable to deploy campaigns that promote activities that may have less of a temperature and day length barrier, such as activities completed inside or those requiring little equipment or space. For example, the most commonly reported leisure-time MVPA is walking at all

ages and the Centers for Disease Control and Prevention has invested many resources into developing national level campaigns to increase walking in the U.S. including Step it Up!, Every Body Walk!, America Walks, and guides to promoting walking in malls and airports.^{15,16} However, environmental factors are a frequently reported barrier to walking and has shown to significantly influence steps per day in a walking intervention.² Other broad reaching interventions that could be incorporated to overcome weather barriers include green space interventions or dog walking, which have been found to be unaffected by seasonal patterns.¹⁷ Given the large number of activities that fall within the MVPA spectrum,¹⁸ activities that may not be as significantly impacted by these weather-related factors or just-in-time adaptive interventions that accommodate for real-time fluctuations in environmental conditions should be promoted.

Limitations

There were limitations to the current study. The Freedson adult cutpoints were used for accelerometer reduction, which may misclassify activity intensity based on individual characteristics. However, this reduction technique is the most used and accepted, allowing comparison across multiple studies.¹⁰ It is acknowledged the conclusions are the results from a post-hoc analysis of a single trial that was not originally powered to assess moderation. However, a simulation study based on observed characteristics of the data determined that there was 80% power to detect differences between treatment groups as small as 10 minutes/day of MVPA, a difference smaller than the observed effect sizes. Also, these are adjusted models that may be prone to Type I error inflation. It is unknown how these results would translate to other populations in a different part of the world, as places get hotter and colder than Chicago, and would therefore result in different outcomes. Additionally, weather data was pulled from a single Chicago site and did not collect specific location information for each participant to more accurately represent the temperature and precipitation in their location. Future research should replicate these results to test validity and identify the effect of weather on MVPA in other populations and locations. In addition, future research could investigate how the type of activities individuals engage in is influenced by weather-related factors. The study also had many strengths, including the objective measurement of MVPA over the entire baseline and intervention phase, and randomization of participants to an intervention to increase MVPA or an active control condition, allowing an unbiased analysis of how the dynamic effects of a PA intervention are moderated by environmental factors. Additionally, the study's location in Chicago allowed examination of intervention effects across a wide range of temperatures and day lengths. Finally, the study sample was diverse, providing a large age range, spanning different phases of life across early to middle-aged adults, and participants with diverse educational and income backgrounds, allowing for greater generalizability.

CONCLUSIONS

Results reveal day length and temperature have a significant moderating effect on the effect of an intervention to increase MVPA during a multicomponent behavioral intervention. This suggests when designing PA interventions in adults, strategies to overcome weather-related barriers should be considered. Such approaches might include fostering activities that are

less contingent upon optimal weather conditions, or incorporating tailored approaches that accommodate seasonal, temperature, and day length influences that might otherwise function to decrease MVPA.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Table 1

Participant Characteristics

Variable	Decrease sedentary behavior (n=109)	Increase physical activity (n=96)	p-values for difference
Age (years)	33 (12)	33 (10)	0.85
BMI (kg/m ²)	27.7 (6.3)	28.9 (7.9)	0.22
Female, n (%)	82 (75)	75 (79)	0.53
Ethnicity, n (%)			
Asian/Pacific Islander	12 (11)	12 (13)	
Black/African American	18 (17)	29 (31)	
White	65 (60)	44 (46)	0.16
More than one race	3 (3)	3 (3)	
Hispanic/Latino	11 (10)	7 (7)	
Education, n (%)			
Associate's/Some college or less	27 (24.8)	34 (35.8)	
Bachelor's degree	23 (21)	23 (24)	0.11
Some graduate school or greater	59 (54)	38 (40)	
Marital status, n (%)			
Married or living with partner	47 (43)	34 (36)	
Single/separated/divorced	62 (57)	61 (64)	0.29

Notes: Data are presented as mean (SD), unless otherwise stated.

Table 2Natural Environmental and Physical Activity Variables by Season During the MBC Study^a

Variables	Spring Mean (SD)	Summer Mean (SD)	Fall Mean (SD)	Winter Mean (SD)
Number of unique study days	275	276	273	226
Average temperature (°F)	51.0 (13.2)	75.0 (5.9)	55.9 (13.8)	27.1 (11.2)
Precipitation (inches)	0.89 (0.21)	0.16 (0.39)	0.10 (0.32)	0.09 (0.22)
Day length (hours)	13.3 (1.1)	14.6 (0.4)	11.1 (1.1)	9.8 (0.7)
Minimum temperature (°F)	41.8 (11.9)	65.6 (5.9)	46.8 (12.8)	20.4 (12.4)
Maximum temperature (°F)	60.1 (15.4)	83.0 (6.7)	63.8 (15.0)	33.6 (11.5)
Total number of observation days	1,301	1,422	1,590	993
Baseline sedentary (minutes/day) ^b	550 (86)	535 (86)	541 (105)	533 (95)
Baseline light (minutes/day) ^b	282 (82)	298 (82)	294 (99)	271 (94)
Baseline MVPA (minutes/day) ^b	34 (26)	34 (24)	30 (24)	33 (26)

^aApril 2005–April 2008.^bActivity minutes/day adjusted for accelerometer wear time.

MVPA, moderate to vigorous physical activity; MBC, Make Better Choices

Table 3

Predicted Daily Means (95% CI) Moderate to Vigorous Physical Activity by Treatment Phase and Average Temperature for Each Season

Fixed temperature value/Treatment group	Baseline	Follow-up	Change from baseline to follow-up
27° F			
Increase PA	27.0	35.1	8.11 (4.27, 11.94)
Decrease SB	27.0	28.6	1.65 (−1.85, 5.15)
Difference			6.45 (1.70, 11.21)
51° F			
Increase PA	28.5	40.7	12.15 (9.88, 14.41)
Decrease SB	28.5	30.6	2.07 (−0.11, 4.25)
Difference			10.10 (7.03, 13.13)
75° F			
Increase PA	30.1	46.3	16.19 (13.15, 19.23)
Decrease SB	30.1	32.5	2.48 (−0.73, 5.69)
Difference			13.71 (9.54, 17.88)
56° F			
Increase PA	28.8	41.8	12.99 (10.78, 15.19)
Decrease SB	28.8	31.0	2.15 (−0.05, 4.35)
Difference			10.84 (7.80, 13.87)
<i>p</i> -value for three-way tx by time by average temperature interaction			0.015

^a Average temperature reported represents average temperature for each seasonal period in Table 2. Continuous variable of average temperature used in regression equation. Season not controlled for in analysis.

tx, treatment; PA, physical activity; SB, sedentary behavior

Table 4

Predicted Daily Means (95% CI) Moderate to Vigorous Physical Activity by Treatment Phase and Average Day Length for Each Season

Fixed day length ^a /Treatment group	Baseline	Follow-up	Change from baseline to follow-up
9.8 hours			
Increase PA	28.8	36.4	7.62 (3.10, 11.24)
Decrease SB	28.8	31.5	2.65 (−0.81, 6.12)
Difference			4.96 (0.20, 9.73)
13.3 hours			
Increase PA	28.3	42.9	14.65 (12.27, 17.03)
Decrease SB	28.3	30.1	1.87 (−0.55, 4.28)
Difference			12.78 (9.47, 16.10)
14.6 hours			
Increase PA	28.1	45.3	17.26 (14.08, 20.43)
Decrease SB	28.1	29.6	1.57 (−1.70, 4.85)
Difference			15.69 (11.26, 20.11)
11.1 hours			
Increase PA	28.6	28.8	10.23 (7.57, 12.88)
Decrease SB	28.6	31.0	2.36 (0.17, 4.90)
Difference			7.87 (4.34, 11.39)
<i>p</i> -value for three-way tx by time by average day length interaction			0.002

^a Average day length reported represents average day length for each seasonal period in Table 2. Continuous variable of average day length used in regression equation. Season not controlled for in analysis.

tx, treatment; PA, physical activity; SB, sedentary behavior