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Using Twitter to investigate seasonal variation in physical activity in urban green space

Helen Roberts, Jon Sadler and Lee Chapman

To understand how the benefits of outdoor physical activity in urban green spaces are transferred to human populations, consideration must be given to when people are using them, what they are using them for and what factors may affect the use of space. This paper critically evaluates the use of crowdsourced Twitter data in an assessment of physical activity engagement in urban green spaces in an attempt to investigate the potential of these data in investigating urban socio-ecological interactions. A case study is presented in which Twitter data are used to assess the variance of physical activity engagement between two seasons (summer and winter). A number of factors including meteorology, park characteristics and amenities, and the role of organised sports events are explored in order to explain the observed findings. Understanding how physical activity engagement in urban green space varies seasonally is important in ensuring policy interventions to increase physical activity are targeted most effectively.

Key words Birmingham; UK; outdoor physical activity; Twitter; crowdsourcing; ecosystem services; urban green space

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Introduction

Approaches to public health have become increasingly interdisciplinary in attempts to account for socio-ecological interactions (Collins *et al.* 2000; Forget and Lebel 2001; Kabisch *et al*. 2015), with increasing consideration given to the potential salutogenic impacts of the surrounding physical environment on human health (Tzoulas *et al.* 2007). Ecosystem approaches to health systematically recognise that environmental systems support human health and wellbeing, and seek to place human populations at the centre of considerations about development and ecosystem management. Socio-ecological approaches look to improve human health through the management of natural ecosystems alongside more direct forms of interventions into human behaviour. However, isolating the links between human wellbeing and ecosystem processes is difficult because of the complexity of interactions between ecological and social systems (Kittinger *et al.* 2009). Moreover, attempts to investigate ecological processes and human well-being derive from disparate spheres. Accordingly, there is a need for greater integration of themes across environmental and health research (Haines-Young and Potschin 2010; Liu *et al.* 2007) to better understand the complex, multi-scale mechanisms underlying the correlative relationships observed (Scholes *et al.* 2013).

Green space has been shown to have numerous beneficial effects for human populations, through approaches loosely assembled under the umbrella of ecosystem services (Costanza *et al.* 1997; MEA 2005). This paper focuses on the important role that urban green spaces provide as locations for a range of outdoor physical activities within cities. Participation in physical activity is seen as increasingly important, given the levels of obesity and weight-related poor health conditions in the United Kingdom. In England, 62% of adults are overweight or obese (HSCIC 2015), putting them at increased risk of diseases such as diabetes, cancer, heart disease, stroke and liver disease. Alongside other lifestyle behaviours such as a balanced diet, not smoking and not drinking to excess, physical activity and exercise are a means of reducing obesity and therefore risk to these diseases (GOS 2007). Physical activity is therefore being promoted as a

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public health priority and numerous interventions have been implemented to encourage active participation of people in high-risk groups. Parks have been shown to have a significant role in supporting the physical activity of local populations (Han *et al.* 2013). Indeed, the role of parks and urban green spaces as a location for activity interventions and as a resource to satisfy current physical activity requirements has, for a while, been recognised by decision-makers (Bedimo-Rung *et al.* 2005; Sallis *et al.* 1998). The effectiveness of these schemes, however, is dependent on engagement with physical activity, which in itself has been found to correlate with a number of factors, including accessibility of space (Sallis *et al.* 1990), park facilities (Krenichyn 2006), neighbourhood aesthetics (Hoehner *et al.* 2005), traffic (Troped *et al.* 2001), social support from friends and family (Brownson *et al.* 2001) and perceived neighbourhood safety (Suminski *et al.* 2005).

The public health literature has identified parks and urban green spaces as common places for physical activity for urban populations (Bedimo-Rung *et al.* 2005; Cohen *et al.* 2007; Maas *et al.* 2008; McCormack *et al.* 2010). Indeed, studies focused on specific subgroups have found them to be a significant resource for physical activity for adolescent girls (Cohen *et al.* 2006), the elderly (Tinsley *et al.* 2002), children (Muñoz, 2009) and those living in low-income households (Lee 2005). Such studies have been useful in emphasising the role of urban green spaces in providing space and opportunity for engagement with physical activity; however, they typically lack specificity on the relationship between park locations and their use by urban populations (Kaczynski *et al.* 2008). More recently attention has been focused on the effect of park size, park features and distance from residential area on physical activity levels; however, the effects of seasonality and weather conditions are still largely overlooked as a potential determinant of outdoor physical activity (Ergler *et al.* 2016; Humpel *et al.* 2002; Tucker and Gilliland 2007).

In the United Kingdom, the substantial variation in weather within and between seasons may have a significant effect on the use of parks as spaces for outdoor physical activity. Adverse weather conditions have been previously identified as a personal barrier to engagement with a variety of outdoor activities (Lee and Maheswaran 2011). Rainfall, cold temperatures and icy conditions have all been identified as meteorological barriers across a range of social groups, with particular effect on the engagement of physical activity in the elderly and young children (Belza *et al.* 2004; Edwards *et al.* 2015). Despite the progress into understanding the associations between meteorological conditions and physical activity that these studies have provided, there has been recognition that attempts to investigate these relationships have lacked objective assessment (Chan *et al.* 2006), relying too heavily on self-report methods of data capture. Substantial variation in daylight hours between seasons (ranging from 8 hours in winter to 16 hours in summer) is also an important factor in explaining physical activity variation (Beighle *et al.* 2008). However, it has been given relatively less attention than other influential factors such as age (Floyd *et al.* 2011), gender (Kaczynski *et al.* 2009) and ethnicity (Gordon-Larsen *et al.* 2000). It is essential for policy-makers to understand the seasonal variation in physical activity, and the mechanisms behind this variation, to ensure that interventions aimed at increasing physical activity can be implemented most effectively (Beighle *et al.* 2008).

Geographical approaches are well placed to investigate the relations between seasonality and social practices and studying cultural practices may provide insight into the varying effect of the seasons on different social groups; with the potential for this information to generate novel positive interventions for enhancing outdoor experience (Hitchings 2010). Previous methodologies investigating seasonal variation in engagement with outdoor physical activity have followed two main approaches: observational and subjective reporting. While these approaches have their merits, there are significant shortcomings to both. Observational methods, such as counting individuals (Joseph and Maddock 2016; Suminski *et al.* 2008), are time consuming and lack longitudinal depth. Subjective reporting methods, such as surveys and self-report questionnaires (Salmon *et al.* 2003), suffer similar time and cost constraints as well as other limitations such as participant recall bias (Sallis and Saelens 2000). The methodological challenges of both these traditional approaches mean that innovative methods are needed if research is to engage more actively with the effect of seasonality on physical activity behaviours.

This paper presents one such method, using crowdsourced data from the social network Twitter, to provide information about individual engagement and use of urban green spaces for physical activity. The benefits of this approach to the researcher are extensive, including a reduction in both financial and time expenditure, given that the data are freely available to download at as frequent a time interval as necessary. Given that financial and time restraints are cited as reasons why studying seasonal variation in outdoor behaviours has been neglected (Ergler *et al.* 2016), the opportunities afforded by this approach are considerable. Access to social network data also provides a larger sample size than is feasibly obtained through observation and survey approaches and may also provide more heterogeneous data than highly

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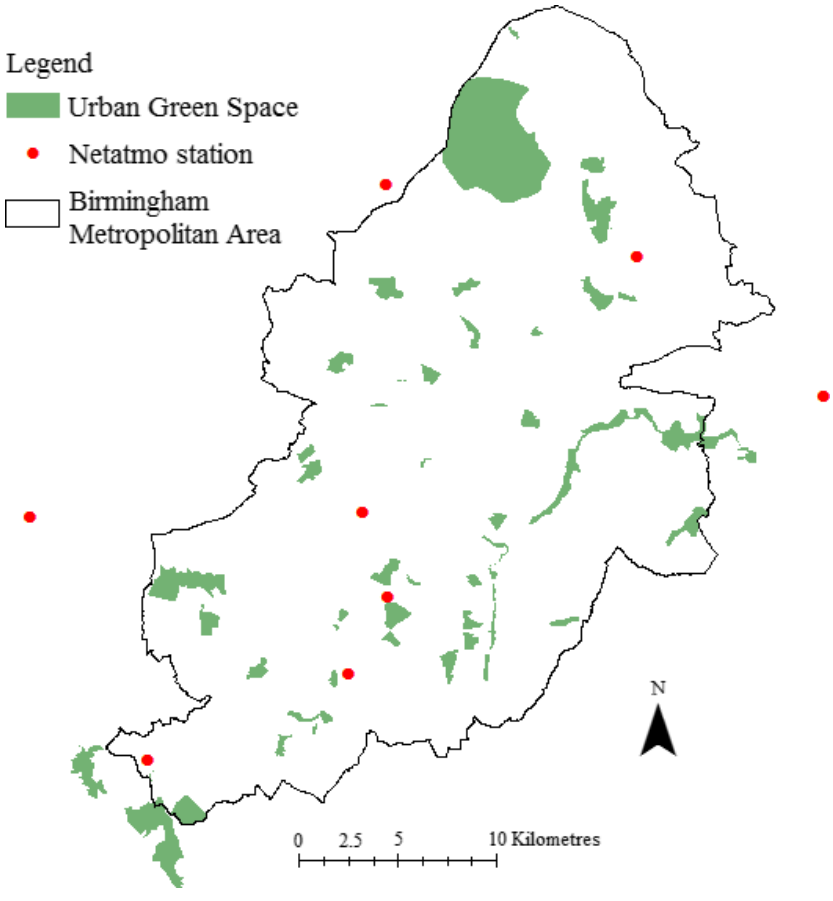

Figure 1 The locations of the 46 urban green spaces in Birmingham included in the study sample and the position of the Netatmo stations used to provide meteorological data

structured methods due to the diversity of social network users (Elwood 2008).

This paper investigates the seasonal differences in physical activity participation in urban green spaces reported by individuals on Twitter, and the impact of a number of variables on how and when urban populations on Twitter report using urban green spaces as a location for outdoor physical activity. The influence of meteorological variables (temperature and rainfall), hours of darkness, weekday, organised sports events (OSE) and park characteristics are considered. In doing so, the ways in which people use urban green space, and how this varies over a range of temporal scales is examined. This new methodological approach to capturing physical activity engagement within urban green space is presented in an attempt to overcome limitations of previous research. Rather than being reliant upon the results of subjective reporting and observational data, this new approach demonstrates the potential of using crowdsourced and social network data in socio-ecological investigations.

The methodological approach and data sources utilised in this paper are now introduced. An analysis and subsequent discussion of results in relation to the findings of previous research are then presented. Twitter as a source of data for investigating reported seasonal variation in urban outdoor physical activity is then evaluated before the paper draws its overall conclusions.

Methodology

Study area

Forty-six urban green spaces were selected for study over a 3-month summer period (June–August 2015) and a 3-month winter period (December 2015–February 2016). The urban green spaces were located in Birmingham, the second largest city in the United Kingdom with an estimated population of 1.1 million (ONS 2014). Within the metropolitan area, there are nearly 600 parks, public open spaces and nature reserves (BCC 2016), the most of any European city.

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Figure 1 depicts the locations of the urban green spaces in this study sample. The locations were chosen to reflect the diversity of urban green spaces found across the city and included parks and nature reserves of a range of sizes and with differing amounts of woodland, grassland, water and other characteristics. They offer a range of services and facilities and are found within different types of neighbourhoods.

Measurement of physical activity using Twitter

Created and launched in 2006, Twitter is a free microblogging service which enables users to communicate through short statuses and messages of up to 140 characters in length. Any registered Twitter user connected to the internet via a smart device or computer has the ability to receive and share information in real time. Twitter now reports 313 million monthly active users (Twitter 2017) with over 500 million tweets uploaded per day (Internet Live Stats 2017). This makes Twitter a highly influential player in the distribution of information and opinion (Mathioudakis and Koudas 2010). Twitter data have already been used successfully in a diverse array of urban disciplines, including land use classification (Frias-Martinez and Frias-Martinez 2014; Zhan *et al.* 2014), environmental monitoring (Demirbas *et al.* 2010) and sentiment analysis (Hauthal and Burghardt 2013; Klettner *et al.* 2013).

Various studies suggest that social media is altering how individuals communicate and socially interact with one another (Kwak *et al*. 2010; Zhao and Rosson 2009), with micro-blogging sites like Twitter bringing a new type of communication technology for people to engage with. The posts an individual can create are limited in length, can have multimedia attachments and can reach extensive networks of people in the public domain within a short space of time. Research is beginning to address interesting questions in terms of the social functions of these micro-blogging sites and the information they can provide about engagement with virtual social behaviour. Indeed, Java *et al*. (2007) have suggested three types of distinct user activities on Twitter: information seeking, information sharing and social activity. Naaman *et al*. (2010) go further to describe how much of the information shared on Twitter can be categorised as opinion and 'about me' information, highlighting how Twitter is fast becoming a self-promotion tool for many of its users. Twitter has been found to diverge from the norms of authentic social interaction in that links between users are often not reciprocated (Huberman *et al.* 2008; Kwak *et al.* 2010); for example, one can follow a user who does not follow them back, creating unidirectional social interactions. This, and the ability to maintain virtual interactions with people who an individual has no contact with in their day to day life are cited reasons as to why people engage with Twitter (Zhao and Rosson 2009).

In this study, Twitter was used to create a corpus of tweets for investigation. English language tweets were downloaded via Twitter's REST API using the park names as queries. Duplicates and retweets were removed during pre-processing. Tweets were then manually screened and those referencing physical activity were collated into the dataset used herein. This methodology created a corpus of tweets containing reference to physical activity being undertaken in urban green spaces in Birmingham. The tweets captured a range of information including the type of activity being engaged with, the weather conditions that exercise was undertaken in, who the Twitter user was exercising with, the length of time exercise was undertaken and mentions of notable events experienced during exercise. A small number of tweets from the corpus are presented in Table I, demonstrating the variety of information the tweets contained.

Measurement of meteorological variables

The procurement of atmospheric data at both high spatial and temporal resolutions over long periods of time remains challenging to urban climate researchers (Chapman *et al.* 2015). The discipline has begun to investigate the potential for citizen science and crowdsourcing for providing data appropriate for studies requiring atmospheric observations at high spatial and

Table I A small subset of tweets from the dataset

Tweet	*Date of Tweet creation*
'Just cycled me and my legs up to Lickey Hills. Very Lickey up 'ere. #lickeyhills #birmingham #legs'	8 August 2015
'Head to Muntz Park for FREE #ParkLives Zumba (Fri 3.15pm)'	23 July 2015
'Great football, great drama, great sportmanship, great day at the Aston Park Rangers Football Tournament today'	20 June 2015
'A muggy 8 miles through Sutton Park this morning, felt surprisingly good, after Tuesday nights tough race! #running #fitness'	25 June 2015
'Welcome to Billesley Common. It's blustery, it's cold, it's December rugby'	5 December 2015
'Lovely run in Summerfield Park with my son. What an awesome way to start 2016 #lovebrum #couchto5k'	1 January 2016
'Bird walk at Moseley Bog. We were listening to a black cap. #Urbannature #moseleybog #birdsong'	18 February 2016
'2 Superb Fitness Sessions this evening at Cofton Park with Coaches Matt & Dom'	11 January 2016

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Figure 2 A word cloud depicting the variety of physical activities reported in the received tweets. Word size is reflective of activity frequency, with larger activities appearing more frequently in the tweets

temporal resolutions (Muller *et al.* 2013; Overeem *et al.* 2013).

Netatmo weather stations (www.netatmo.com) provide a compromise between citizen science and crowdsourcing. The devices are commercially available to interested individuals who wish to monitor atmospheric parameters inside or outside a building. As a smart device, their in-built wifi connectivity enables the data each device collects to be transferred to a unified cloud server for storage where it is then made available for download through the Netatmo API. These devices are part of the 'internet of things' which is playing an increasingly important role in providing crowdsourced data (Muller *et al.* 2015). Netatmo weather stations were used to provide measurements of temperature (°C) and rainfall (mm) across the study area. Measurements are taken by each device at a temporal resolution of 5 minutes and then uploaded to the Netatmo server infrastructure and made immediately available for download through the RESTful API. The closest outdoor Netatmo stations to the study sites were selected for study (Figure 1). The position of these stations was sufficient to capture city-wide sufficient variability in the meteorological variables under study, despite low spatial coverage.

Statistical analysis

After presentation of the relevant descriptive statistics for the datasets, the outputs of a number of statistical tests are presented to determine seasonal differences and any relationships present. Following a Shapiro-Wilk test for normality, a paired sample *t*-test was used to determine seasonal differences in summer and winter weekday and weekend tweet frequencies. Descriptive statistics are presented for rainfall and temperature, and the seasonal differences discussed. Spearman's rho are used to determine the relationships between a number of park attributes (park area, percentage tree cover, area of standing water, park amenities) and physical activity tweet frequency in order to better understand the spatial distribution and variability of physical activity tweets. Finally, Wilcoxon signed rank tests are used to determine the difference

Table II Seasonal differences in the frequency that each activity is mentioned in the received physical activity tweets. Normalised winter values are presented alongside actual tweet frequencies to account for differences in sample sizes of total tweets received in winter and summer

	Winter	*Winter (normalised values)*	*Summer*
Active Parks activities	22	33	272
Running	150	222	161
Walking	223	331	153
Cycling	31	46	45
Water sports	16	24	23
Team sports	36	53	105
Outdoor fitness	35	52	25
'Fun' sports	1	1	26

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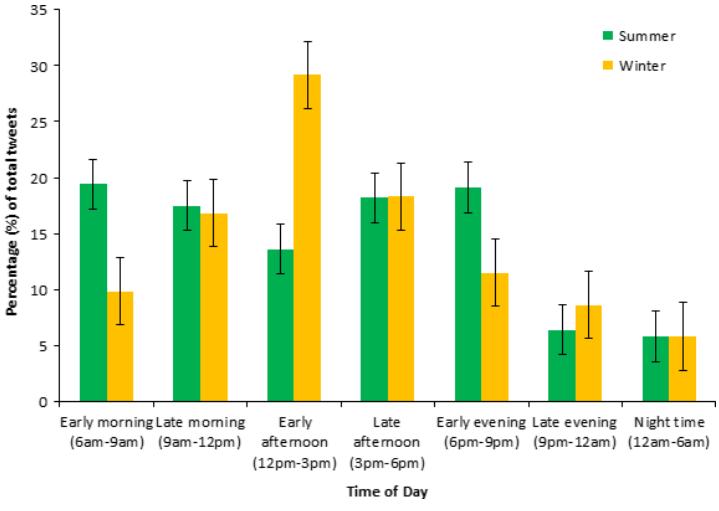

Figure 3 Seasonal differences in the average number of physical activity tweets received on each day of the week

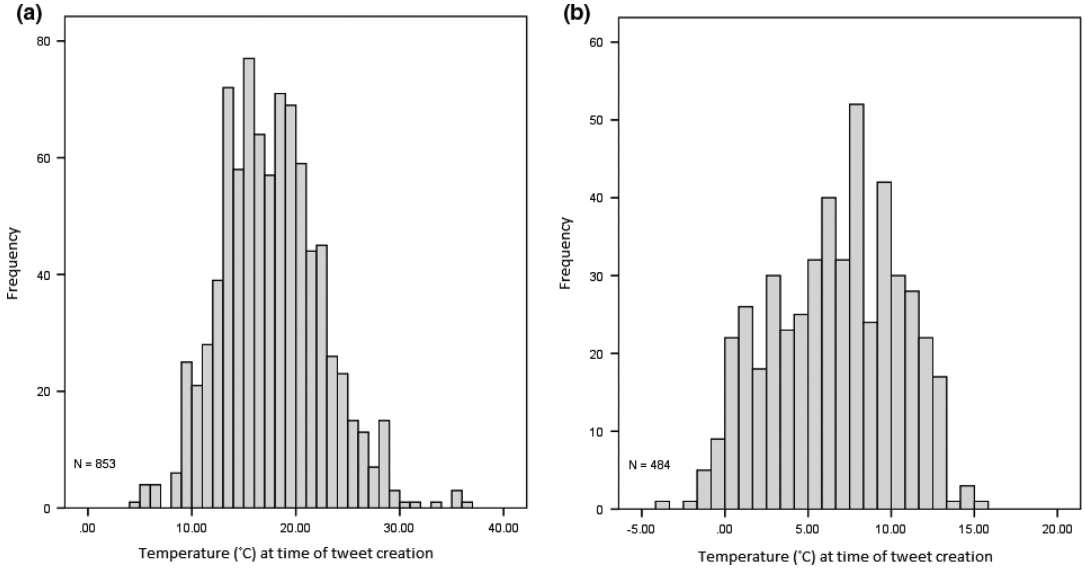

Figure 4 The frequency of temperatures (°C) at the time of tweet creation for (a) summer and (b) winter

in tweet numbers between summer and winter and also the effect of OSE on this difference.

Results

A total of 2847 tweets were recorded in summer and 1920 were recorded in winter. Relative proportions show 59.8% of all tweets were received in summer and 40.2% in winter. Of these total tweets captured, 853 and 484 tweets were identified as relating to physical activity in summer and winter respectively. The relative proportions of physical activity tweets received in each season was generally reflective of, but slightly more differentiated than, the proportion of total tweets received in each season, with 63.8% received in summer and 36.2% in winter. The types of physical activities captured were highly diverse (Figure 2).

The influence of season on received physical activity tweets

Tweets mentioning physical activity occurred in more parks in summer than in winter. Twenty-nine parks showed a higher number of tweets mentioning physical activity in summer than in winter, eight parks showed higher numbers of tweets in winter than in summer and nine parks showed no change between seasons.

ISSN 2054-4049 doi: 10.1002/geo2.41

Table III Descriptive statistics for temperatures (°C) and presence of rainfall at the time of tweet creation for summer and winter

	Summer	*Winter*
Mean	17.6	6.6
Minimum value	4.8	-3.9
Maximum value	36.3	15.8
Range	31.5	19.7
Standard deviation	4.9	3.8
% of dry hours	95.6	4.4
% of wet hours	94.2	5.8

A Wilcoxon signed rank test identified a significant increase in tweets mentioning physical activity from winter to summer (z=–3.418m, p<0.005). An effect size of –0.504 was calculated representing a medium change in the number of tweets mentioning physical activity between seasons according to Cohen's criteria for effect size.

With regard to the different types of activities recorded, the total number of activities occurring in the sampled locations increased from 19 in winter to 33 in summer, suggesting an increased variety in the physical activities taking place. As well as the increase in the number of physical activities taking place, it is also possible to identify a seasonal difference in the frequency that each activity is mentioned in tweets (Table II). Using the number of tweets received in each season, six of the eight activity types showed an increase in tweet frequency from winter to summer. However, using normalised values, which identify differences between seasons with sample size variation taken into account, only three activities show increases from winter to summer: Active Parks activities (+239), team sports (+52) and fun sports (+25). Cycling and water sports remain proportionally the same in both seasons. A decrease in tweet frequency from winter to summer was observed for walking (–178), running (–61) and outdoor fitness (–27).

Giving consideration to temporal variation in the number of physical tweets received over the course of a 7-day week, a paired-sample t-test identified a significant difference between summer weekday and winter weekday received tweets (t=–10.988, p<0.005), however there was no significant difference found between winter weekend and summer weekend received tweets. The total number of tweets received per weekday in summer and winter followed a similar pattern (Figure 3). Decreases in tweet numbers occurred after the weekend, which then increased to a midweek peak on Wednesday. Tweet numbers then fell on Thursday and Friday before increasing again at the weekend.

Investigations into the seasonal differences between when tweets were created showed early mornings and early evenings to be popular in summer compared with winter (Figure 4). The most popular time of creation for tweets in winter was found to be early and late afternoon.

The influence of meteorological variables on received physical activity tweets

To understand the role meteorology plays in the significant differences identified in the number of physical activity tweets received in winter and summer, each tweet was assigned a temperature value and rainfall binary (wet or dry). Using these hourly rainfall measurements, 92.9% of tweets were found to be created when no rainfall was recorded in summer, compared with 90.7% in winter. Both seasons showed significant numbers of tweets being created when no rainfall was recorded despite significant variation in mean temperatures at the time of tweet creation (Table III).

The difference between the temperatures at which tweets were created in summer and winter was less pronounced and a large range of temperatures were recorded for both seasons. When comparing the two seasons, summer temperatures were found to have a greater range than the winter temperatures at which tweets were created (Table III).

The influence of park characteristics and organised sports events on received physical activity tweets

To understand better the spatial distribution and variability of physical activity tweets, a number of park characteristics were considered, including the park area, area of standing water, percentage tree cover and available facilities.

A spearman's rho showed that park area and the number of tweets mentioning physical activity, in both summer [rs(45)=0.181, p=0.230] and winter [rs(45) =0.228, p=0.127], were not significantly related. Similarly, there was no significant relationship between the area of standing water and the number of physical activity tweets for both summer [rs(45)=–0.059, p=0.699] and winter [rs(45)=0.092, p=0.542]. The percentage of park tree cover was also insignificant for the number of winter tweets [rs(45)=0.188, p=0.210], but significant for the summer [rs(45)=0.233, p<0.05]. Positive significant patterns were found between the number of park amenities relevant to physical activity and the number of physical activity tweets for both summer [rs(45)=0.480, p<0.05] and winter [rs(45) =0.462, p<0.05].

Whilst undertaking the categorisation of the received tweets it was clear that a number related to OSE. To ascertain if the presence of OSE is affecting engagement with physical activity, a comparison of tweets relating to independent physical activity and engagement with OSE was undertaken. Independent

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Table IV Mean temperature (°C) and presence of rainfall at the time of tweet creation for independent physical activity and OSE in winter

	OSE – winter	*Independent physical activity – winter*
% created when wet	11.5%	7.5%
% created when dry	88.5%	92.5%
Mean temperature (°C) at time of tweet creation	7.2	6.2

activity was classified as an individual or individuals engaging at their own time in any type of physical activity compared with OSE which were defined as pre-planned activities led by a specific individual or company. A total of 70.6% of all physical activity tweets in summer were related to an OSE compared with 45% of total physical activity tweets in winter.

Parks where only independent physical activity tweets were present occurred more in winter than in summer. Eighteen parks showed a higher number of tweets mentioning independent physical activity in winter than summer, 13 parks showed a higher number of tweets mentioning independent physical activity in summer than winter and 15 parks showed no change in the number of tweets mentioning independent physical activity (of which 14 out of the 15 detected no tweets mentioning independent physical activity). The opposite was true for OSE; with parks where only tweets about OSE occurred more in summer than in winter. Twenty-nine parks showed a higher number of tweets mentioning OSE in summer than in winter, four parks showed a higher number of tweets mentioning OSE in winter than in summer and 13 parks showed no change in the number of tweets mentioning OSE (of which 10 out of 13 detected no tweets mentioning OSE in both winter and summer).

A Wilcoxon signed rank test found the increase in tweets mentioning independent physical activity from summer to winter not to be significant. For OSE, however, a significant difference was found in the number of tweets mentioning OSE in the summer compared with the winter. A significant increase in tweets was identified from winter to summer (z=–3.933, p<0.005) and an effect size of –0.58 was calculated, representing a large change in the number of tweets mentioning OSE between the seasons based on Cohen's criteria for effect size.

Comparing the influence of meteorological variables on engagement with physical activity in winter, there was little difference in the mean temperature at which tweets relating to OSE or independent physical activity were recorded. A large difference was recorded, however, between the percentages of tweets created when wet/dry (Table IV), with OSE demonstrating a higher proportion of tweets created in wet conditions.

Discussion

Higher frequencies of physical activity tweets were received in summer compared with winter and an increased number of parks were shown to have people tweeting about engaging with physical activity in summer. While Twitter data are merely a proxy for physical activity engagement, and these observations are not representative of total engagement as not all individuals will tweet while taking part in physical activity, they do reflect the common notion that more people engage with outdoor physical activity in summer than in winter (Ma *et al.* 2006; Merchant *et al.* 2007; Tudor-Locke *et al.* 2004). This is explained by poorer weather conditions in winter and the effect this has on an individual's desire and motivation to engage with physical activity (Hug *et al.* 2009; Matthews *et al.* 2001). The continued, albeit lower, frequency of physical activity tweets in winter is also consistent with findings from previous studies (Pivarnik *et al.* 2003; Uitenbroek 1993).

When examining the seasonal differences identified between the types of activities, the higher diversity of activities reported in the summer is perhaps reflective of the increase of opportunities available for individuals to engage with. The decreases observed in the frequency of, for example, Active Parks activities from summer to winter is unsurprising. The observed lack of tennis, badminton, basketball and other court-based activities reflects their conceptualisation as traditionally summer sports. A number of factors were considered in an attempt to find reasoning for the seasonal variation in physical activity tweets identified. The significant reduction of weekday tweets in winter compared with both winter weekend and summer weekday and weekend received tweets may be explained by variation in daylight hours (Cooper *et al.* 2010; Tucker and Gilliland 2007). This notion is substantiated when consideration is given to the time of day that tweets were created. A large number of tweets were created in early mornings in summer reflecting changes in daylight hours capturing people using the early morning light to get out and exercise before work. In contrast, in winter, early and late afternoon were the most common time of day for physical activity. A plethora of studies have found that darkness inhibits outdoor physical activity in a variety of social groups, including low-income women (Hoebeke 2008), children of varying ethnicities (Brockman *et al.* 2011; Thompson *et al.* 2001) and the elderly (Bjornsdottir *et al.* 2012; Zimring *et al.* 2005). Self-reported reasons for this relate to a fear of crime and worries about personal safety (Bjornsdottir *et al.* 2012; Lee 2005).

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The influence of temperature on physical activity presented in previous studies is varied. Some studies identify temperature as a significant factor explaining the variance of engagement with physical activity between seasons (Nikolopoulou *et al*. 2001), while others describe a less obvious effect that is hard to differentiate from other influential factors (Humpel *et al.* 2002). In this study, temperature did not have a significant impact on physical activity tweet frequency for either season. There are a myriad of factors which can be influential in determining an individual's response to cold weather, and the effect it has on their participation in outdoor physical activity, which makes generalising these relationships unwise. To highlight a few such factors, the role of clothing in mitigating low outdoor temperatures (Nikolopoulou *et al.* 2001; Thorsson *et al.* 2004) may help explain the lack of a significant impact of temperature on physical activity in both seasons, as well as the influence of habit in an individual's routine (Aarts *et al.* 1997) and their intrinsic motivation to remain active (Annesi, 2002) irrespective of temperature. The presence of park characteristics, such as shade, can also mitigate against high summer temperatures. While causality cannot be directly inferred, it may be that the positive association between percentage tree cover and physical activity tweets in summer is due to the presence of tree cover and thus shade, an important ecosystem service to individuals engaging with physical activity, cooling the environment and helping to mitigate against warm temperatures (Bastion *et al.* 2012). It may also be a reflection of the types of aesthetic environments that individuals like to engage with while they exercise and a tree-filled space may be more appealing than spaces with different predominant landscape. Such observations could help urban planners create spaces with which individuals are more inclined to engage with and utilise. Indeed, there is potential for future research to make use of the multimedia attachments, which users commonly upload within their tweets, to examine the types of landscapes that are commonly engaged with for exercise.

The impact of rainfall was more pronounced with the majority of physical activity tweets in both seasons being created in dry conditions (Edwards *et al.* 2015; Tucker and Gilliland 2007). While this is an expected observation, it is exactly because these observations are straightforward that Twitter provides a valuable source of data for empirical research into the effects of seasonality on outdoor physical activity. This finding extends to the different types of physical activity examined. With minimal exceptions, all showed similar proportions of tweets being created in wet or dry conditions, with the majority of tweets for all activities being created when dry. Caution is needed, however, before making inferences from these data. It is not possible to know if individuals stop exercising in the rain or if they continue to exercise but refrain from tweeting about their activity because of concerns about getting their phones wet.

Concurrent with previous studies which find the presence of amenities to increase participation in outdoor exercise (Brodersen *et al.* 2005; Davison and Lawson 2006), the presence of certain amenities was found to influence the frequency of physical activity tweets. This is unsurprising given that some activities require certain facilities, especially team sports such as cricket, football, badminton, basketball, tennis, rugby and frisbee, while cycling activities predominantly took place in locations with tarmacked paths or designated trails. Such consolidation of previous findings and the identification of expected outcomes again highlight the potential of Twitter data as a source of empirical data for urban green space research and in providing urban planners with an evidence base for decision-making. For example, Twitter data could be used to justify and monitor the implementation of a new cycle path. Twitter data have provided information on engagement with different types of physical activity and could be used to identify areas of low engagement with cycling where a path may help facilitate increased engagement. After implementation, continued data capture could monitor cycling activity and provide evidence for any change in engagement with cycling.

It is also important to draw on the impact of OSE on reported physical activity engagement and how this may explain the seasonal variation observed in some activity tweet frequencies. A variety of OSE took place in both the summer and the winter, contributing significantly to the role of urban green spaces as locations for engagement with physical activity. Twitter was found to be an important platform through which information about these OSE were shared. The continued provision of organised events through winter has previously been found to help increase engagement with physical activity (Sallis *et al*. 1998). Despite the observed reduction of OSE in winter in this study, the remaining OSE may explain the increased reporting of physical activity by Twitter users in less favourable weather conditions compared with independent physical activity. Indeed, for individual activities repeated precipitation events which are common in British winters may decrease levels of physical activity for extended periods (Tucker and Gilliland 2007), thus the provision of group activities may help motivate these individuals to take part regardless of the weather. Higher tweet frequencies of individuals participating in OSE when rainfall was recorded compared with tweet frequencies of independent physical activity perhaps shows the importance of these events in encouraging individuals to participate in outdoor physical activity when they may typically be disinclined to do so. However, this

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cannot be directly inferred from the data as it is not possible to capture those engaging with independent physical activity or OSE and not reporting this in their tweets. Concerns about getting a smart phone wet may stop members of both activity groups tweeting in these conditions.

Evaluation of the use of Twitter data

This paper has demonstrated that Twitter data can provide information on individuals' outdoor physical activity behaviours and used to investigate seasonal variation in physical activity in urban green space, adding to the results obtained using observational and recall-based methods reported in the literature. Twitter data were successfully used to investigate the reporting of engagement by individuals with physical activity in urban green spaces as well as providing insight into the range of activities with which individuals are participating. Twitter data provide greater spatial cover than some previous studies and the data collection is considerably less time and cost intensive than the methods traditionally employed in this field. The observations obtained from Twitter reflected well established notions of physical activity engagement and how this varies seasonally. This, and the significantly lower research cost of using Twitter data compared with traditional observational and subjective reporting methods makes it a valuable source of data for empirical research in this field. The paper has demonstrated the utility of information provided in tweets in exploring the tweeting behaviours and outdoor physical activity practices associated with seasonal variations. Such information is helpful in providing a more nuanced understanding of the complexities of seasonal variation in engagement with outdoor physical activity in urban green spaces. It should be noted, however, that this paper uses a relatively small dataset of tweets, thus caution is needed before inferring wide generalisations from these results. Larger tweet datasets should be collated to infer robust conclusions about physical activity variation in a particular green space or in a particular community. While this paper demonstrates the method for obtaining such datasets, it is beyond the scope of this paper and the dataset presented herein to make such inferences.

While this paper has demonstrated the contextual information that Twitter can provide about the types of activities that individuals choose to engage with, there is a limit to how informative 140 characters can be. There remain some significant limitations in the demographic information provided. For example, age (Uitenbrook 1993) and ethnicity (Ma *et al.* 2006) have both been identified as influential factors in explaining the physical activity behaviours of individuals, information for which is not available from Tweets. Without demographic information it remains challenging to establish the influential cultural dynamics operational in forming green space experience from Twitter data.

It is also important to highlight the inherent biases in a dataset obtained from social networks given that the users of social networks do not reflect the diversity of the urban population they are investigating (Schwartz and Hochman 2014). Not all members of the urban population will own a smart phone or actively engage with social networks. This has implications for investigating use of green space by specific sectors of the population. For example, older people (75+) show disproportionate levels of dis-engagement with these types of technologies (Zickuhr and Madden 2012). A lack of specific demographic information may limit the utility of the information that Twitter data can provide in creating targeted policies aimed at increasing engagement with outdoor physical activity amongst certain age or ethnic groups. While more investigation is needed to quantify the utility of tweet frequencies as a proxy for park visitation, the similar patterns found in this paper compared with previous studies may suggest (Ma *et al.* 2006; Merchant *et al.* 2007; Tudor-Locke *et al.* 2004) that Twitter data could be used to approximate park visitation and physical activity engagement; however, this would require a comparison between actual visit frequencies and received tweet frequencies to see if tweet data can accurately represent real visit data.

To promote year round engagement with outdoor physical activity, it is necessary to understand the seasonal variation in such activity among the population (Ergler *et al.* 2016). The potential of providing information related to individuals' outdoor exercise behaviours to policy-makers and urban planners is extensive (De Valck *et al.* 2016) and offers the possibility of enhancing the outdoor experiences of the individual, and encouraging year round engagement with outdoor physical activity in the green spaces they manage. This could be achieved through the development of interventions based around observations obtained from Twitter data. Planners could also capitalise on the promotive power of Twitter to encourage outdoor physical activity among its users, creating tweetable spaces, activities and challenges that users could engage with while exercising in urban green space.

Monitoring of council-led physical activity programmes may also be possible through the capture of Twitter data and be a way to justify the continued running, or provide evidenced examples, of successful initiatives. For example, in Birmingham, the Active Parks and Parkslive programmes run by Birmingham City Council both provide opportunities for individuals to engage with a range of free physical activities in green spaces across the city. The #Parklives hashtag

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was often used by Twitter users detailing their engagement with these activities. By monitoring tweets containing this hashtag it would be possible for organisers to capture engagement, or use the other information users provide in their tweets such as who they are with or how they feel. Twitter could also provide a platform for organisers to actively engage with users to gain feedback on these sessions, by getting users to include specified hashtags in their tweets which could then be searched for through the Twitter API.

Conclusion

Seasonal variations in physical activity tweets between summer and winter were investigated. Significant seasonal variation in received physical activity tweets was identified and a number of factors were investigated in an attempt to explain this variation; including meteorological variables (rainfall and temperature), daylight hours, park characteristics and amenities, and the presence of organised sports events.

The influence of rainfall was more significant than temperature on engagement with physical activity for both seasons. The presence of park amenities proved important in explaining the occurrence of a number of specific physical activities at certain locations, again in both seasons. Relationships between physical activity tweets and meteorology were found to be less significant than those presented in other studies. Other factors were found to be important in explaining the complex behaviour of engagement with physical activity, with the presence of organised sports events being particularly influential in increasing physical activity tweet frequencies in summer.

This paper has successfully demonstrated the potential of Twitter data in investigating seasonal variation in physical activity in urban green spaces. Tweeting itself is a cultural practice and the information obtained from its users can inform investigations of seasonality in the social norms and cultural practices associated with outdoor physical activity. This method of data collection offers researchers a number of benefits over traditional observational and subjective reporting methods, including a less time and labour intensive data collection process and greater spatial coverage. However, some limitations of this method still remain. Little information about the demographic of individuals making up the dataset is available and until this is addressed it may limit the utility of results for policymakers.

While these limitations remain, this paper has found Twitter data to be a useful addition to the methodological approaches employed to gather information on physical activity in urban green space. It offers a creative way to overcome methodological challenges associated with more traditional approaches and its successful employment consolidates the notion that geographic-based approaches are well placed to investigate the relationship between seasonality and outdoor physical activity behaviours.

References

Aarts H, Paulussen T and Schaalma H 1997 Physical exercise habit: on the conceptualization and formation of habitual health behaviours *Health Education Research* 12 363–74

Annesi J 2002 Self-motivation moderates effect of exercise-induced feelings of adherence *Perceptual and Motor Skills* 94 467–75

Bastian O, Haase D and Grunewald K 2012 Ecosystem properties, potentials and services – the EPPS conceptual framework and an urban application example *Ecological Indicators* 21 7–16

Bedimo-Rung A, Mowen A and Cohen D 2005 The significance of parks to physical activity and public health: a conceptual model American *Journal of Preventative Medicine* 28 159–68

Beighle A, Alderman B, Morgan C and Masurier G 2008 Seasonality in children's pedometer-measured physical activity levels *Research Quarterly for Exercise and Sport* 79 256–60

Belza B, Walwick J, Shiu-Thornton S, Schwartz S, Taylor M and LoGerfo J 2004 Older adult perspectives on physical activity and exercise: voices from multiple cultures *Preventing Chronic Disease* 1 A09

Birmingham City Council (BCC) 2016 Parks and nature conservation (www.birmingham.gov.uk/parks) Accessed 4 May 2016

Bjornsdottir G, Arnadottir S and Halldorsdottir S 2012 Facilitators of and barriers to physical activity in retirement communities: experiences of older women in urban areas *Physical Therapy* 92 551–62

Brockman R, Jago R and Fox K 2011 Children's active play: self-reported motivators, barriers and facilitators *BMC Public Health* 11 461

Brodersen N, Steptoe A, Williamson S and Wardle J 2005 Sociodemographic, developmental, environmental, and psychological correlates of physical activity and sedentary behavior at age 11 to 12 *Annals of Behavioral Medicine* 29 2–11

Brownson R, Baker E, Housemann R, Brennan L and Bacak S 2001 Environmental and policy determinants of physical activity in the United States *American Journal of Public Health* 91 1995–2003

Chan C, Ryan D and Tudor-Locke C 2006 Relationship between objective measures of physical activity and weather: a longitudinal study International *Journal of Behavioural Nutrition and Physical Activity* 3 21

Chapman L, Muller C, Young D, Warren E, Grimmond C, Cai X-M and Ferranti E 2015 The Birmingham Urban Climate Laboratory: an open meteorological testbed and challenges of the smart city *Bulletin of the American Meteorological Society* 96 1545–60

Cohen D, Ashwood J, Scott M, Overton A, Evenson K, Staten L, Porter D, McKenzie T and Catellier D 2006 Public parks and physical activity among adolescent girls *Pediatrics* 118 e1381–9

ISSN 2054-4049 doi: 10.1002/geo2.41

Cohen D, McKenzie T, Sehgal A, Williamson S, Golinelli D and Lurie N 2007 Contribution of public parks to physical activity *American Journal of Public Health* 97 509–14

Collins J, Kinzig A, Grimm N, Fagan W, Hope D, Wu J and Borer E 2000 A new urban ecology *American Scientist* 88 416–25

Cooper A, Page A, Wheeler B, Hillsdon M, Griew P and Jago R 2010 Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project *International Journal of Behavioral Nutrition and Physical Activity* 7 1

Costanza R, d'Arge R, Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O' Neill R, Paruelo J, Raskin R, Sutton P and Belt M 1997 The value of the world's ecosystem services and natural capital *Nature* 387 253–60

Davison K and Lawson C 2006 Do attributes in the physical environment influence children's physical activity? A review of the literature *International Journal of Behavioral Nutrition and Physical Activity* 3 1

De Valck J, Broekx S, Liekens I, De Nocker L, Van Orshoven J and Vranken L 2016 Contrasting collective preferences for outdoor recreation and substitutability of nature areas using hot spot mapping *Landscape and Urban Planning* 151 64–78

Demirbas M, Bayir M, Akcora C, Yilmaz Y and Ferhatosmanoglu H 2010 Crowd-sourced sensing and collaboration using twitter World of Wireless Mobile and Multimedia Networks (WoWMoM), 2010 *IEEE International Symposium IEEE* 1–9 IEEE, Montreal

Edwards N, Myer G, Kalkwarf H, Woo J, Khoury P, Hewett T and Daniels S 2015 Outdoor temperature, precipitation and wind speed affect physical activity levels in children: a longitudinal cohort study *Journal of Physical Activity & Health* 12 1074–81

Elwood S 2008 Volunteered geographic information: future research directions motivated by critical, participatory, and feminist GIS *GeoJournal* 72 173–83

Ergler C, Kearns R and Witten K 2016 Exploring children's seasonal play to promote active lifestyles in Auckland, New Zealand *Heath and Place* 41 67–77

Floyd M, Bocarro J, Smith W, Baran P, Moore R, Cosco N, Edwards M, Suau L and Fang K 2011 Park-based physical activity among children and adolescents *American Journal of Preventive Medicine* 41 258–65

Forget G and Lebel J 2001 An ecosystem approach to human health *International Journal of Occupational and Environmental Health* 7 3–38

Frias-Martinez V and Frias-Martinez E 2014 Specteral clustering for sensing urban land use using Twitter activity *Engineering Applications of Artificial Intelligence* 35 237–45

Gordon-Larsen P, McMurray R and Popkin B 2000 Determinants of adolescent physical activity and inactivity patterns *Pediatrics* 105 e83

Government Office for Science (GOS) 2007 *Tackling obesity: future choices – obesity systems atlas* Government Office for Science, London

Haines-Young R and Potschin M 2010 The links between biodiversity, ecosystem services and human well-being in **Raffaelli D and Frid C** eds *Ecosystem ecology: a new synthesis* BES Ecological Reviews Series, Cambridge 110–39

Han B, Cohen D and McKenzie T 2013 Quantifying the contribution of neighborhood parks to physical activity *Preventive Medicine* 57 483–7

Hauthal E and Burghardt D 2013 Extraction of location-based emotions from photo platforms in **Krisp J** ed *Progress in location-based services* Springer, New York NY

Health and Social Care Information Centre (HSCIC) 2015 *Statistics on obesity, physical activity and diet: England 2015* Health and Social Care Information Centre, London

Hitchings R 2010 Seasonal climate change and the indoor city worker *Transactions of the Institute of British Geographers* 35 282–98

Hoebeke R 2008 Low-income women's perceived barriers to physical activity: focus group results *Applied Nursing Research* 21 60–5

Hoehner C, Ramirez L, Elliott M, Handy S and Brownson R 2005 Perceived and objective environmental measures and physical activity among urban adults *American Journal of Preventive Medicine* 28 105–16

Huberman B, Romero D and Wu F 2008 Social networks that matter: Twitter under the microscope *First Monday* 14 1–9

Hug S, Hartig T, Hansmann R, Seeland K and Hornung R 2009 Restorative qualities of indoor and outdoor exercise settings as predictors of exercise frequency *Health and Place* 15 971–80

Humpel N, Owen N and Leslie E 2002 Environmental factors associated with adults' participation in physical activity: a review *American Journal of Preventative Medicine* 22 188–99

Internet Live Stats 2017 Twitter usage statistics (www.internetlivestats.com/twitter-statistics/#ref-3) Accessed 28 April 2017

Java A, Song X, Finin T and Tseng B 2007 Why we twitter: understanding microblogging usage and communities *Proceedings of the 9th WebKDD and 1st SNA-KDD 2007 Workshop on Web Mining and Social Network Analysis* ACM 56–65 Springer, New York NY

Joseph R and Maddock J 2016 Observational park-based physical activity studies: a systematic review of the literature *Preventive Medicine* 89 257–77

Kabisch N, Qureshi S and Haase D 2015 Human–environment interactions in urban green spaces – a systematic review of contemporary issues and prospects for future research *Environmental Impact Assessment Review* 50 25–34

Kaczynski A, Potwarka L and Saelens B 2008 Association of park size, distance and features with physical activity in neighborhood parks *American Journal of Public Health* 98 1451–6

Kaczynski A, Potwarka L, Smale B and Havitz M 2009 Association of parkland proximity with neighborhood and park-based physical activity: variations by gender and age *Leisure Sciences* 31 174–91

Kittinger J, Coontz K, Yuan Z, Han D, Zhao X and Wilcox B 2009 Toward holistic evaluation and assessment: linking ecosystems and human well-being for the Three Gorges Dam *EcoHealth* 6 601–13

Klettner S, Huang H, Schmidt M and Gartner G 2013 Crowdsourcing affective responses to space *Kartographische Nachrichten* 2 66–72

Krenichyn K 2006 'The only place to go and be in the city': women talk about exercise, being outdoors, and the meanings of a large urban park *Health and Place* 12 631–43

ISSN 2054-4049 doi: 10.1002/geo2.41

Kwak H, Lee C, Park H and Moon S 2010 What is Twitter, a social network or a news media? *Proceedings of the 19th International Conference on World Wide Web ACM* 591–600 Raleigh, NC

Lee A and Maheswaran R 2011 The health benefits of urban green spaces: a review of the evidence *Journal of Public Health* 33 212–22

Lee Y 2005 Gender differences in physical activity and walking among older adults *Journal of Women & Aging* 17 55–70

Liu J, Dietz T, Carpenter S, Alberti M, Folke C, Moran E, Pell A, Deadman P, Kratz T, Lubchenco J, Ostrom E, Ouyang Z, Provencher W, Redman C, Schneider S and Taylor W 2007 Complexity of coupled human and natural systems *Science* 317 1513–16

Ma Y, Olendzki B, Li W, Hafner A, Chiriboga D, Hebert J, Campbell M, Sarnie M and Ockene I 2006 Seasonal variation in food intake, physical activity, and body weight in a predominantly overweight population *European Journal of Clinical Nutrition* 60 519–28

Maas J, Verheij R, Spreeuwenberg P and Groenewegen P 2008 Physical activity as a possible mechanism behind the relationship between green space and health: a multilevel analysis *BMC Public Health* 8 1

Mathioudakis M and Koudas N 2010 Twittermonitor: trend detection over the twitter stream in *Proceedings of the 2010 ACM SIGMOD International Conference on Management of Data* 1155–8 ACM, Indianapolis IN

Matthews C, Freedson P, Herbert J, Stanek E, Merriam P, Rosal M, Ebbeling C and Ockene I 2001 Seasonal variation in household, occupational and leisure time physical activity: longitudinal analyses from the seasonal variation of blood cholesterol study *American Journal of Epidemiology* 153 172–83

McCormack G, Rock M, Toohey A and Hignell D 2010 Characteristics of urban parks associated with park use and physical activity: a review of qualitative research *Health and Place* 16 712–26

MEA 2005 *Ecosystems and human well-being 5* Island Press, Washington DC

Merchant A, Dehghan M and Akhtar-Danesh N 2007 Seasonal variation in leisure time physical activity among Canadians *Canadian Journal of Public Health* 98 203–8

Muller C, Chapman L, Grimmond C, Young D and Cai X 2013 Sensors and the city: a review of urban meteorological networks *International Journal of Climatology* 33 1585–600

Muller C, Chapman L, Johnston S, Kidd C, Illingworth S, Foody G, Overeem A and Leigh R 2015 Crowdsourcing for climate and atmospheric sciences: current status and future potential *International Journal of Climatology* 35 3185–203

Muñoz S 2009 *Children in the outdoors: a literature review* Sustainable Development Research Centre, Edinburgh

Naaman M, Boase J and Lai C 2010 Is it really about me? Message content in social awareness streams *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* 189–92 ACM, Savannah GA

Nikolopoulou M, Baker N and Steemers K 2001 Thermal comfort in outdoor urban spaces: understanding the human parameter *Solar Energy* 70 227–35

Office for National Statistics (ONS) 2014 *Mid-2014 mid-year population estimates* BDB2015/04 Birmingham Demographic Briefing, BCC

Overeem A, Robinson J, Leijnse H, Steeneveld G, Horn B and Uijlenhoet R 2013 Crowdsourcing urban air temperatures from smartphone battery temperatures *Geophysical Research Letters* 40 4081–5

Pivarnik J, Reeves M and Rafferty A 2003 Seasonal variation in adult leisure-time physical activity *Medicine and Science in Sports and Exercise* 35 1004–8

Sallis J, Bauman A and Pratt M 1998 Environmental and policy interventions to promote physical activity *American Journal of Preventive Medicine* 15 379–97

Sallis J, Hovell M, Hofstetter C, Elder J, Hackley M, Caspersen C and Powell K 1990 Distance between homes and exercise facilities related to frequency of exercise among San Diego residents *Public Health Reports* 105 179

Sallis J and Saelens B 2000 Assessment of physical activity by self report: status, limitations, and future directions *Research Quarterly for Exercise and Sport* 71 409

Salmon J, Owen N, Crawford D, Bauman A and Sallis J 2003 Physical activity and sedentary behaviour: a population-based study of barriers, enjoyment and preference *Health Psychology* 22 178–88

Scholes R, Reyers B, Biggs R, Spierenburg M and Duriappah A 2013 Multi-scale and cross-scale assessmentsof social–ecological systems and their ecosystem services *Current Opinion in Environmental Sustainability* 5 16–25

Schwartz R and Hochman N 2014 *The social media life of public spaces: reading places through the lens of geo-tagged data* Locative Media Routledge, New York NY

Suminski R, Poston W, Market P, Hyder M and Sara P 2008 Meteorological conditions are associated with physical activities performed in open-air settings *International Journal of Biometeorology* 52 189–97

Suminski R, Poston W, Petosa R, Stevens E and Katzenmoyer L 2005 Features of the neighborhood environment and walking by US adults *American Journal of Preventive Medicine* 28 149–55

Thompson J, Davis S, Gittelsohn J, Going S, Becenti A, Metcalfe L, Stone E, Harnack L and Ring K 2001 Patterns of physical activity among American Indian children: an assessment of barriers and support *Journal of Community Health* 26 423–45

Thorsson S, Lindqvist M and Lindqvist S 2004 Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden *International Journal of Biometeorology* 48 149–56

Tinsley H, Tinsley D and Croskeys C 2002 Park usage, social milieu, and psychosocial benefits of park use reported by older urban park users from four ethnic groups *Leisure Sciences* 24 199–218

Troped P, Saunders R, Pate R, Reininger B, Ureda J and Thompson S 2001 Associations between self-reported and objective physical environmental factors and use of a community rail-trail *Preventive Medicine* 32 191–200

Tucker P and Gilliand J 2007 The effect of season and weather on physical activity: a systematic review *Public Health* 121 909–22

Tudor-Locke C, Bassett Jr D, Swartz A, Strath S, Parr B, Reis J, Dubose K and Ainsworth B 2004 A preliminary study of one year of pedometer self-monitoring *Annals of Behavioral Medicine* 28 158–62

ISSN 2054-4049 doi: 10.1002/geo2.41

Twitter 2017 Twitter usage/company facts (https://about.twitter.com/company) Accessed 28 April 2017

Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kazmierczak A, Niemela J and James P 2007 Promoting ecosystem health in urban areas using green infrastructure: a literature review *Landscape and Urban Planning* 81 167–78

Uitenbrook D 1993 Seasonal variation in leisure time physical activity *Medicine and Science in Sports and Exercise* 25 755–60

Zhan X, Ukkusuri S and Zhul F 2014 Inferring urban land use using large-scale social media check-in data *Networks and Spatial Economics* 14 647–67

Zhao D and Rosson M 2009 How and why people twitter: the role that micro-blogging plays in informal communication at work *Proceedings of the ACM 2009 International Conference on Supporting Group Work* 243–52 ACM, Sanibel Island FL

Zickuhr K and Madden M 2012 Older adults and internet use *Pew Internet & American Life Project* 6

Zimring C, Joseph A, Nicoll G and Tsepas S 2005 Influences of building design and site design on physical activity: research and intervention opportunities *American Journal of Preventive Medicine* 28 186–93

ISSN 2054-4049 doi: 10.1002/geo2.41